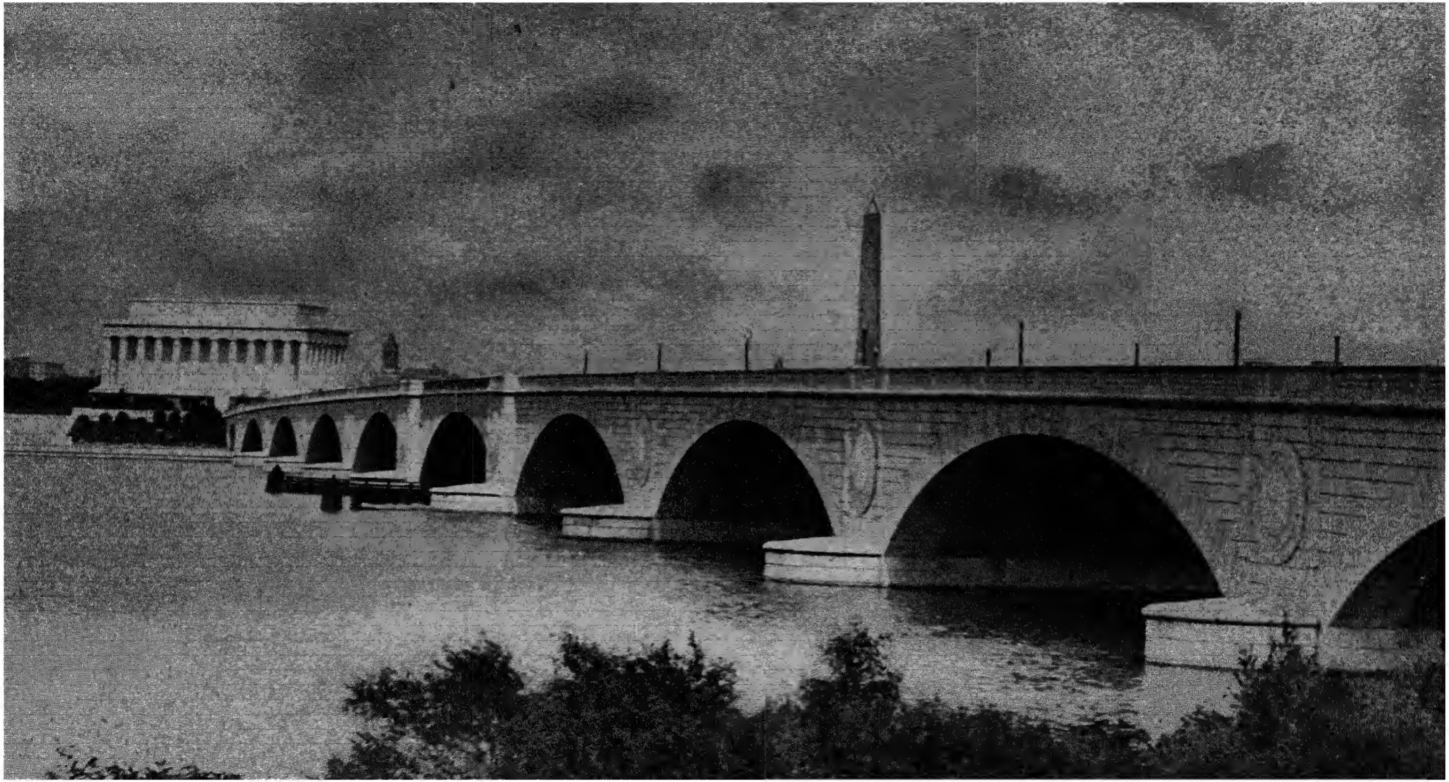
THE STONE INDUSTRIES



(*Frontispiece*)

Arlington Memorial Bridge, Washington, D. C. (*Photo by the author.*)

On one bank of the Potomac stands a nation's shrine, the marble-columned Lincoln Memorial; on the other side Arlington National Cemetery, where heroes sleep; the broad river between is bridged with a majestic sweep of granite arches; and, overtopping all, a stately spire of stone erected in memory of immortal Washington.

THE STONE INDUSTRIES

Dimension Stone Crushed Stone

Geology Technology Distribution Utilization

BY

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PREFACE TO THE SECOND EDITION

Since the first edition of this volume appeared, the stone industries have suffered the most severe depression in their history. Now they are emerging toward a more normal rate of production, and there is definite prospect of increasing activity in building which should promote further gains. In this new edition most of the tables have been revised to show the latest available figures, and corresponding changes have been made in the text to embody the most recent data.

Centers of production have shown so little change during recent years that only minor corrections were needed. The sections on technology of quarrying and fabrication as covered in the first edition were based largely on the author's personal observation and study of hundreds of quarries and stone-finishing mills, and they reflect modern practice so comprehensively that little revision was required. Although refinements in equipment and methods are constantly in evidence, no fundamental modifications have occurred since 1934; therefore, the portrayal of conditions as set forth in the new edition approximates a true picture of the stone industries as they exist today.

OLIVER BOWLES.

WASHINGTON, D. C.,
January, 1939.

PREFACE TO THE FIRST EDITION

No book adequately covering the stone industries has been available recently. Building stones were described many years ago by Dr. George P. Merrill in his well-known volume, *Stones for Building and Decoration*, the third edition of which appeared in 1910 and is now out of print. The venerable doctor was planning a much-needed revision, but his plans were cut short by his sudden death in 1929. Other books, such as E. C. Eckel's *Building Stones and Clays* and C. H. Richardson's volume of the same title, are valuable for certain phases of the stone industries. Various bulletins on granites, marbles, and slates by T. Nelson Dale contain a wealth of detailed information, chiefly of geological import. Bulletins of several State geological surveys describe the stone resources and developments of their States quite thoroughly, but few have been published during recent years. Certain textbooks for engineers and architects contain brief and frequently quite inaccurate references to stone as a material of construction. None of the publications mentioned presumes to cover the many ramifications of the stone industries; the purpose of this volume is to fill this gap in American technical literature.

The author began his studies of the stone industries in Minnesota in 1912; and during the years since 1914, as a quarry specialist of the United States Bureau of Mines, he has visited and made intimate examinations of hundreds of quarries and mills scattered throughout many States. Results of successive detailed studies were embodied in a series of reports, several of which are now out of print. The background of first-hand knowledge thus gained was the chief incentive that urged him toward the laborious task of compiling this book.

Acknowledgment is made to the officials of the United States Bureau of Mines for permitting wide reference to its published information. Grateful acknowledgment is rendered to many who have assisted in preparing the material. In presenting a broad subject in a comprehensive manner innumerable occasions for errors occur, and while misstatements may still remain, review by competent authorities and repeated revisions have greatly minimized this liability. The author desires to make special mention of noteworthy service by Harold Ladd Smith of Proctor, Vt.; J. B. Newsom of Bloomington, Ind.; J. L. Mann and R. M. Richter of Bedford, Ind.; Charles H. Behre of Evanston, Ill.; W. S. Hays of Philadelphia; Lawrence Childs and Jules Leroux of New York, and Société Anonyme de Merbes-Sprimont, Brussels, Belgium. Several quarry operators have kindly reviewed sections of the book

relating to their industries. The chapters devoted to crushed and broken stone involved so much detail regarding deposits and their geology that the services of State geologists were enlisted for review and comment. The author desires to express to them his keen appreciation of their most helpful and hearty cooperation. To Paul M. Tyler, Paul Hatmaker, and H. Herbert Hughes, associates of the author in the United States Bureau of Mines, acknowledgment is due for many helpful suggestions. Miss A. T. Coons of the Bureau, whose intimate knowledge of the stone-producing industries is widely recognized, supplied valuable comment and advice. To my wife, Eva H. Bowles, grateful acknowledgment is made for assistance in proof reading, and to my sons, George and Edgar, for corrections and revisions of certain sections.

OLIVER BOWLES.

WASHINGTON, D. C.
July, 1934

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INTRODUCTION

Stone, the foundation and superstructure of the everlasting hills, is the most abundant of all material things. It is the earth itself on which we live. Although widespread in occurrence to a point that breeds contempt, stone is used so extensively that it touches the extremes of human activity—from lowly shattered fragments trampled under foot to flawless statuary marbles that provide material for the highest forms of art. Between these two extremes stone and its products are essential to multitudes of industries; they take part in the affairs of practically every community and touch the life of nearly every person. To cover in detail so broad a field would far exceed the scope of a single volume, but an attempt is made to present a moderately comprehensive picture of the properties and characteristics of stone, the methods of removing it from its native beds and preparing it for use, its many applications in modern industry, production centers at home and abroad, and the outstanding economic features of each branch of this far-reaching industry.

Remarkable progress has been made in the quarrying and utilization of stone. Its application to practical use was one of the oldest human activities, extending far back before the earliest records, for the name "stone age" is applied to that period of history of which knowledge is conveyed to us only by crude tools and implements of stone fashioned by the aborigines. Neolithic man, using a crooked reindeer antler as a mining tool, dug flint balls from the chalk cliffs of England and shaped them into spear heads or other implements. During later periods American cliff-dwellers constructed crude homes with walls of stone. The slow progress made through long ages from these primitive beginnings makes interesting chapters in ancient history but has little bearing on the stone quarrying of today. Development of the industries in their present scope has been comparatively recent. From caverns and sheltering slabs of rock constituting the earliest human habitations to stately mansions of cut and polished stone is a long journey, and every step of progress has been marked by accelerated speed. Thus, although the industries have existed for many centuries, the greatest advances in manufacture and use have been crowded into the last fifty years. To give a true picture of the status of these industries today is the purpose of this book.

PART I

GENERAL FEATURES OF THE STONE INDUSTRIES

CHAPTER I

EXTENT AND SUBDIVISION

Extent of the Industry.—Stone production is the most widespread of all industries in this country except agriculture, for rock deposits are exploited in every State and in a great majority of the counties. In the United States the average annual production of stone of all kinds, including slate, from 1927 to 1931, was more than 176,500,000 short tons, with an annual value exceeding $216,300,000. About 2,800 quarries and mines are in operation, and the number of employees in them and in directly associated plants is approximately 90,000.

Delivery of the enormous tonnage of stone to innumerable markets is an important transportation item, involving rail, water, and truck haulage. Coal and oil burned in quarries, mills, cement plants, and lime kilns constitute an appreciable part of the fuel production of the country, and the machinery and explosives used create an extensive market for factory products. Thus, through its wide scope and complex ramifications stone holds a dominant place in the Nation's industry and exerts a pronounced influence on national growth and development.

Major Divisions of the Industry. *Dimension Stone.*—The oldest use of stone and the one that has become increasingly important through the centuries is for building purposes. At first, rough walls were built of scattered boulders, but with increasing knowledge of the use of tools stone was quarried from solid ledges. Before the age of explosives and before steam and compressed air were utilized quarrying was slow and laborious; nevertheless, the pyramids and obelisks represent remarkable engineering skill. These magnificent stone structures were built by innumerable slaves, whose labor extended over many decades. Since ancient times stone has been a favorite material for constructing the finest buildings. Growth and development in art and architecture have been expressed in noble structures, and we are indebted to the enduring nature of stone for the preservation of many invaluable records of past achievement.

The hewing of stone from its native beds with only the crudest hand tools made it too costly for use, except in temples, palaces, and similar structures. With the invention of explosives, the advent of steam power, and, later, the use of electricity and compressed air, blocks of stone were obtained with increasing ease, and rock became more and more widely available as a building material. From cathedrals, bridges, and other

great public works it has found its way to smaller and less pretentious structures, even to small one-family homes.

Dimension stone is used for other purposes than for building. In ancient times a pile of stones was raised as a memorial, and from this custom has developed the monument or headstone cut from suitable rock and carved with a fitting inscription. Stone blocks are also used for paving streets and roads and for the manufacture of curbing. In addition, stone has many special uses, such as for electrical switchboards and blackboards.

Crushed Stone.—The use of crushed or broken stone developed much later than that of dimension stone. Stone sledged by hand, usually by convict labor, was used in road construction, and this use increased rapidly. With the invention of cement and with mass production made possible through explosives, power crushers, and screens the broken-stone branch of the industry grew with phenomenal speed. In 1886 the output of crushed and broken stone was smaller than that of dimension stone, while in 1930 it was thirty times as great. Concrete aggregate, road stone, and ballast are the principal products.

Stone Used in Manufacturing Processes.—For practically all the uses mentioned above, stone is employed crude and untreated. It may be shaped, polished, crushed, or ground, but its physical and chemical properties remain essentially unchanged. In many modern industries, however, stone undergoes physical and chemical changes, the final product being quite different from the raw material in both form and composition. Outstanding examples are limestones manufactured into cement, lime, or calcium carbide; dolomite made into refractories; and crushed sandstone fused with other products into glass.

Varieties of Stone Used.—The more common rocks used in commerce are granites and related igneous rocks, limestones, marbles, slates, and sandstones. Soapstone also is included as a branch of the dimension-stone industry. Many rocks in commercial use do not properly belong to any of the foregoing groups. When employed as dimension stone they usually are classed with one of the major groups; when used in crushed or broken form they are considered a miscellaneous group.

CHAPTER II

MINERALS AND ROCKS

Distinction between Rock and Stone.—While the words "rock" and "stone" are often regarded as synonyms, there is a definite distinction in their meaning. The term "rock" is applied to a geologic formation in its crude form as it exists in the earth. "Stone" is more properly applied to individual blocks, masses, or fragments that have been broken from their original massive ledges for application to commercial use. Therefore, in chapter I the term "stone" is generally employed because reference is made to manufactured products; in Chapter II "rock" is used because the text relates to geologic formations as they exist in nature before exploitation for economic use.

Relation of Rocks to Minerals.—To understand rocks properly one should be acquainted with minerals, because rocks consist of them. The relationship may be brought out most clearly by comparing minerals with letters and rocks with words. Just as there is a word of one letter, the article "a," so we have rocks made up essentially of a single mineral; for example, limestone, which is the mineral calcite, or sandstone, a form of quartz. Some words are made up of many letters, and in like manner some rocks consist of several minerals; thus, granite consists of feldspar, quartz, mica, and sometimes small quantities of hornblende, magnetite, pyrite, garnet, and other minerals. A knowledge of rock-forming minerals is therefore a necessary preliminary to a well-balanced concept of rocks. It may be mentioned, however, that some rocks consist wholly or partly of natural glass or volcanic dust—materials that cannot properly be classed as minerals.

Rock-forming Minerals.—It is assumed that the reader or student who attempts to gain knowledge of the stone industries through these pages has had at least an elementary course in mineralogy. Those who lack this advantage or who desire to refresh their minds on the subject are referred to textbooks or handbooks on mineralogy, because space will not permit descriptions of minerals or means of their identification.

The important minerals in igneous rocks are feldspars, quartz, mica, hornblende, and augite. Those most abundant in sedimentary rocks are calcite, dolomite, and kaolinite (clay). Minor constituents include chlorite, epidote, tremolite, actinolite, olivine, serpentine, garnet, sphene, zircon, talc, pyrite, marcasite, magnetite, hematite, limonite, and apatite.

Classification of Rocks.—Rocks are classified according to their origin into three great groups—igneous, sedimentary, and metamorphic. Igneous rocks are those that originated from molten masses or magmas more recently regarded as high-temperature solutions. Semiliquid magmas deep within the earth cool more or less slowly as they approach the surface until a condition of solidification is attained. The nature of the resulting rock depends on both the composition of the magma and the rate of cooling. Magmas that cool very slowly at great depth tend to form coarse-grained rocks, such as granites and gabbros, because slow cooling ordinarily promotes coarse crystallization. On the other hand, rapid-cooling magmas form fine-grained rocks, such as basalt and aplite. Some rocks, consisting of relatively coarse crystals scattered throughout a fine-grained ground mass, are known as the "porphyries."

Sedimentary rocks are sometimes referred to as "stratified," because they are formed of sediments laid down in successive strata or layers. The materials of which they are formed are derived from preexisting rocks. Processes of rock decay or disintegration on the surface of the earth, though very slow, are continuous and produce stupendous results through centuries and geologic ages. Alternate frost and heat open innumerable fractures in rocks; chemical agents of the atmosphere or of surface and subterranean waters penetrate them and dissolve part of the rocks. Rain, streams, waves, tides, and glaciers loosen the shattered fragments, grind them up, and transport them far from their sources. Wind, too, is an agent of erosion and transportation. Millions of tons, even cubic miles, of rock are disintegrated by these various agencies and carried away to oceans, lakes, and river beds where they are deposited as sediments. In addition to these products of rock decay, myriads of organisms that inhabit the oceans or lakes secrete calcium carbonate or silica from the water to form their shells, and their skeletal remains add to the accumulations of rock-forming material. Thus, three great processes—rock disintegration, transportation, and redeposition—are now and have been at work for ages. These processes—aided, as has been stated, by organic agencies—have formed most of the sedimentary rocks. Four major types are thus formed—conglomerate, sandstone, shale, and limestone.

Metamorphism means change in form. Rocks of either igneous or sedimentary origin that have been changed profoundly during the course of their existence are known, therefore, as "metamorphic rocks." The chief agencies that produce such changes are pressure, heat, and chemical reaction. Rocks deep in the earth may become plastic under great pressure and high temperature and by earth movement may be tilted or folded into complex forms with a banded or schistose structure. Pressure may cause recrystallization, and thermal waters may dissolve, transport, and reprecipitate many minerals. Thus, new rocks may be formed of a

texture and composition quite different from those of unaltered igneous or sedimentary types.

The principal igneous rocks are granite, aplite, syenite, diorite, gabbro, basalt, diabase, rhyolite, and tuff. Sandstone, conglomerate, shale, limestone, and dolomite constitute the group of sedimentary rocks. The metamorphic group includes gneiss, schist, quartzite, slate, marble, and soapstone. Most of the above-named varieties are defined and described in some detail in various following chapters devoted to discussion of their distribution and exploitation. For those desiring a more thorough treatise several textbooks on petrography are available.

General Distribution of Rocks in the United States.—As may be inferred from the foregoing brief description of the origin of rocks, their occurrence is directly related to the geologic history of each region. The Appalachian district of eastern United States, extending from Maine and Vermont to Georgia, is a rugged, mountainous region that has suffered more or less extreme folding or metamorphism; therefore, as one would expect, metamorphic rocks, such as crystalline marbles, slates, gneisses, and schists, are to be found there. Throughout the district many unaltered rock areas also occur and comprise important deposits of granite, diabase, gabbro, sandstone, and limestone.

Between the Appalachian belt and the Rocky Mountains is a vast area in which characteristic metamorphic rocks, such as marble, slate, and gneiss, occur rarely because this is primarily a region of flat-lying sediments that have been distorted very little by mountain-building forces. Nearly horizontal limestone and sandstone beds are the characteristic commercial rocks of the area comprising the eastern portions of West Virginia, Kentucky, and Tennessee; all of Ohio, Indiana, Illinois, Iowa, Nebraska, North and South Dakota, Kansas, Mississippi, Louisiana, Florida, Oklahoma, southern Minnesota, Wisconsin, and Michigan; and most of Missouri, Arkansas, and eastern Texas. Isolated areas of granite occur in Wisconsin, Minnesota, Missouri, South Dakota, Arkansas, Oklahoma, and eastern Texas.

West of the prairie country is another belt, the Rocky Mountain area, in which the rocks are greatly crumpled and folded. Here again the igneous and metamorphic rocks are abundant. This belt passes through Idaho, Montana, Colorado, and New Mexico. Some of the granites, gneisses, and marbles where accessible, have commercial importance. From the Rocky Mountains to the Pacific Coast igneous rocks, of both the granitic type and the more basic varieties such as basalt and gabbro, are very common. Regional metamorphism has produced marbles and slates, but many unaltered limestones and sandstones are found. Vulcanism of comparatively recent geologic age characterizes much of this great western area; and the resulting rocks, such as lava, rhyolite, andesite, and volcanic tuff, are common. Such rocks are rarely found in the Eastern or Central States.

CHAPTER III

FACTORS GOVERNING ROCK UTILIZATION

Rock Qualities on Which Use Depends.—Although rock is the most abundant of all material things only a small fraction of the occurrences at or near the earth's surface is fit for commerce. Requisite qualities which are variable, depending upon the use to which the stone is to be applied, are covered in following commodity chapters.

Importance of Other Factors Than Quality.—Although utilization depends to a marked degree on physical or chemical adaptability, other factors are equally important. Owners of rock deposits are prone to assign too much importance to the quality of their materials without adequate attention to certain economic factors that affect the success or failure of any stone enterprise. For example, building-stone deposits of most excellent quality would be valueless if situated in northern Alaska because the cost of transportation to the nearest market would be prohibitive.

Available Markets.—A study of market outlets for the type and quality of stone available is essential to most successful operation. If the quarry product is crushed stone or similar material that commands a low price per ton, local markets are more important than those at a distance; favorable transportation, however, may extend the market range, which is also influenced directly by production costs. A low-cost plant can compete in a wider area than a high-cost plant handling the same class of commodities. Present and probable future demand should be considered in relation to the production capacity of plants handling competitive materials within the economic shipping radius. For relatively high-priced products, such as ornamental granites and marbles, transportation is a less formidable item in the total delivered price, and the market range may be nationwide. A wide market area, however, brings them into competition with all other similar materials; successful marketing depends upon quality, workmanship, popularity with consumers, prompt delivery, and aggressive salesmanship.

Diversification of Products.—Practically every quarry and pit can produce a variety of grades and classes of materials. A slate quarry may yield roofing slate, structural and electrical slate, blackboards, roofing granules, and slate flour. A granite quarry may provide monumental stone, cut stone, ashlar, rubble, paving blocks, curbing, and crushed stone. Many operators tend to concentrate on one product and discard as waste

any material that can not be applied to this particular use. For profitable operation in a competitive market diversification of production is desirable, and a market should be sought for all types of materials available in a quarry. Although a certain amount of waste is inevitable the enormous piles of rejected stone in many quarry regions indicate that an inquiry might profitably be conducted into the possibility of more extended utilization of by-products.

Transportation Facilities.—Stone is heavy, and the haulage charge is a considerable proportion of the delivered price; for the lower-priced products it may be the chief item of cost at point of consumption. Trucks now handle local delivery almost universally, and the cost depends primarily on the nature of the roads. They are also being employed to an ever-growing extent for distant delivery, the main incentives being the increasing mileage of hard-surfaced roads and the increasing speed of travel, as trucks carrying 6 to 8 tons now attain a speed of 35 to 50 miles an hour.

For distant markets rail or water facilities are essential. Even though the rock is of superior quality, deposits far from railroads may have little value. Such markets are controlled largely by freight rates. Wherever possible commodity rates should be established. Many railroad companies prefer to haul stone because its imperishable nature permits shipment in open cars.

Transportation by water is becoming increasingly important, as indicated by the recent completion of a deep waterway on the Ohio River, and the great increase in quantities of limestone, gypsum, and cement now conveyed by this means. Attention may be directed to increasing tonnages of limestone carried on the Great Lakes: 13,933,378 tons in 1927; 15,679,551 tons in 1928; and 16,269,612 tons in 1929. Water rates are usually lower than rail rates.

Production Costs.—The success of any stone enterprise depends largely on maintaining low production costs. High-cost plants can exist in a competitive market only where some favorable circumstance, such as superior quality of the stone, by-product utilization, effective sales organization, or rapid delivery, gives them an advantage. Quarrymen must therefore keep abreast of the times in efficiency of methods and equipment. Today low cost depends primarily on plant mechanization.

Only by using some effective system of accounting can a knowledge of costs be obtained. Hence systematized cost-keeping is to be regarded as an important economic factor in conducting any stone enterprise.

Competitive Products.—Stone is meeting increasing competition from metals and synthetic products. Aluminum is employed in place of stone for both interior and exterior use. The movement toward all-metal construction is attracting much attention, while glass, enameled steel, and other ceramic products are finding new and important

uses. Alert stone producers are watching all such trends with exceeding care.

Labor and Wages.—Usually the largest single item in production cost is the amount paid in wages. Abundance or scarcity of labor, the prevailing wage level, and living conditions have an important influence on quarry methods. Scarcity of labor or abnormally high wages encourage more complete mechanization. Most stone producers recognize the value of giving special attention to the health, safety, and comfort of their workers, for by so doing they build up a personnel of steady employees, a condition advantageous to both employer and laborer.

CHAPTER IV

PROSPECTING AND DEVELOPMENT

PROSPECTING

Development work should not be started on a deposit without reasonable assurance of an available mass of rock sufficiently high in quality and abundant in supply for profitable exploitation. Prospecting is often found advantageous in quarries that have long been in operation; it is, in fact, a continuous activity with some companies, which enables them to determine the extent of reserves and to plan future developments intelligently.

If the rock appears in bare outcrop, usually a rough estimate of its quality and extent can readily be made. Sedimentary rocks are, as a rule, fairly constant in composition throughout the same bed or zone of deposition, and the greatest variations are found in passing from one bed to another; therefore, all beds that may be included in a quarry are usually sampled. A cliff or escarpment along a stream or gulley is especially valuable, because it provides a cross section which permits tests of quality at various levels. If such a cross section is not available in nature, test holes are drilled at such intervals as will supply adequate data on the whole area under consideration.

The prospecting method is governed to some extent by the type of operation. If the chemical composition of the rock is of primary importance, as in furnace flux, lime, or cement materials, churn-drill cuttings will supply material for chemical analyses. Drill cuttings are sampled at regular intervals, for example, every 5 feet, and an exact record is kept of the drill hole and depth at which each sample is taken. The distance between samples is governed by the uniformity of the rock. Where analyses lack uniformity samples are taken at closely spaced points while in rock of more constant composition they are obtained at wider intervals.

For dimension-stone and most crushed-stone uses the physical are more important than the chemical properties of a rock. Dimension stone must be free from cracks, of uniform texture, of attractive color, and for some uses capable of taking a polish. For crushed-stone uses rock must have satisfactory strength, soundness and low absorption. Churn-drill samples can not be used for testing these qualities. Core drilling is desirable because it not only provides data on the structure and extent of the deposit, but this type of drill cuts out cylindrical masses suitable for making physical tests. Diamond core drills which are in common

use, consist of a rotating steel drum with black diamonds (carbonados) set in its lower edge. Some of the newer types of extremely hard alloys are now being used as substitutes for diamonds in cutting softer rocks. Shot drills also give satisfactory service; cutting is done with a rotating steel drum fed with steel shot as an abrasive. Prospect-drill cores are usually 3 inches, or smaller, in diameter.

The position and spacing of holes are governed by the nature of the rock. Usually the geology of a region is studied thoroughly. General information regarding the geology usually may be obtained from Federal or State geological reports, although some companies employ trained geologists to work out the structure and relationships of all rock formations associated with an operating or prospective quarry.

No definite rules can be given for the position or arrangement of holes. In flat-lying beds of uniform thickness and fairly constant composition they may be spaced at wide intervals—100, 500, or 1,000 feet; where rocks are folded or tilted, or where changes in composition or structure occur within short distances, they should be spaced more closely. Detailed maps are made for complex deposits. From a map constructed after careful study of exposures the position, thickness, and slope of beds may be determined with fair accuracy. In bedded deposits drill holes usually are projected approximately at right angles to the bedding. To intersect steeply dipping beds inclined drill holes may be required; for this purpose a core drill has advantages over a churn drill, for it may be used to drill holes at any angle, even in a horizontal position if so desired, while except in rare instances churn-drill holes are vertical.

Accurate records of every drill hole are kept, and a map is made showing its exact location. As each core section is removed it is marked, recorded, and stored for future reference. Some large companies maintain fireproof storage sheds for prospect-drill cores.

The direct cost of sinking 5½- to 6-inch churn-drill holes in limestone is 20 to 60 cents a foot. These figures apply to constant drilling by experienced workmen. Drilling harder rocks, such as trap rock and granite, is more expensive, the cost ranging from $1.50 to $6.00 a foot. Core drilling with shot or diamond drills costs $3.00 to $5.00 a foot, depending on the nature of the rock and drilling conditions.

When the extent of a stone deposit is known, the approximate tonnage may easily be determined. Rocks vary somewhat in weight. Merrill[1] compiled tables of the weight of many building stones. The average of 68 granites was 166 pounds per cubic foot; of 36 limestones, dolomites, and marbles, 161 pounds; of 76 sandstones, 141 pounds; and of 4 trap rocks, 182 pounds. Sandstones are the most variable because they differ so much in porosity.

[1] Merrill, G. P., Stones for Building and Decoration. 3d ed., John Wiley & Sons, Inc., New York, 1910, pp. 498-507.

To determine the approximate number of short tons available in a limestone deposit the length, width, and depth in feet, as proved by prospect drilling or other methods, may be multiplied and this product is then multiplied by the average weight per cubic foot (161 pounds) and divided by 2,000. For granite or sandstone the corresponding figure for weight per cubic foot may be substituted. Generally it is deemed unwise to expend the large sum necessary to establish quarries and finishing plants unless as a result of prospecting a reserve of good rock sufficient for at least 20 years' operation is assured. Some companies operating dimension-stone deposits open up quarries at moderate expense and sell their products in rough blocks until the quality of the rock is proved, marketability established, and a definite income assured. In due time finishing mills may be built and equipped.

The determination of overburden is a phase of prospecting. Both the depth and nature of overlying material, whether sand, gravel, clay, or inferior rock, may be learned by drilling or trenching.

STRIPPING

Nature and Thickness of Overburden.—Stripping is the process of removing the overburden of clay, gravel, or sand from the rock surface. Many deposits of marketable rock are overlain with inferior quality rock, which in a sense may be regarded as overburden. However, as methods of removing solid rock, whether barren or useful, are quite distinct from those employed in handling soil, removal of inferior waste rock is to be classed as a quarrying rather than a stripping problem.

Most stone producers are interested in stripping. In certain places quarries are worked in rock formations that appear in bare outcrop, and fortunate owners of such quarries may view their neighbor's stripping problems with a certain degree of complacence. Most commercial rock deposits, however, are covered with varying depths of rock debris. Indeed, the absence of all overburden is not always an unmixed blessing. The writer has observed granite areas where 10 feet or more of soil has preserved the rock almost to the surface, while other parts of the area that were in bare outcrop were altered and discolored too greatly for monumental use to depths of 4 to 8 feet. Removal of such rock as waste is moreover more costly than removing several feet of soil.

The depth of overburden ranges from a few inches to 10, 20, 30, and in exceptional instances even 40 or 50 feet. Likewise, the nature of materials composing it is variable. It may be easily disintegrated loam, sticky plastic clay, sand, gravel, boulders, or even a hardpan that may require blasting.

Stripping usually is a problem of greater magnitude in the crushed than in dimension-stone industries. For crushed-stone uses a great volume of stone must be handled; many quarries produce thousands of

tons a day. This great bulk of material demands rapid widening of quarry walls, and stripping may become continuous. The dimension-stone branches of the industry handle relatively higher-priced products per ton which require much more labor in preparation, and the tonnage produced is correspondingly lower. Working at much greater depths is justified by the more valuable products, and 5 or 10 years may elapse before a new pit is started or a new bench opened.

Clean Stripping.—For certain classes of quarries clean stripping is essential; for others it is immaterial. Purity has first importance for stone applied to chemical uses. Silica and alumina are most undesirable impurities in limestone for lime manufacture and for furnace flux, and such impurities are the chief constituents of the overburden. Clean stripping is therefore essential at such quarries. On the other hand, in the manufacture of portland cement clay is added to the limestone to obtain a proper mixture; hence, if some clay is quarried with the rock and proper care exercised in subsequent addition of clay, no detriment to the product will ensue. Similarly, in dimension-stone production surface debris will not harm the product; it will be separated from quarry blocks in due course and removed with other quarry waste. In best quarry practice, however, as much of the overburden as can be handled conveniently is removed before underlying rock is quarried.

Stripping Difficulties Due to Erosion Cavities.—Limestone and marble are exceptionally difficult to strip because the slow erosion of circulating water follows joints and cracks and thus wears away the rock surface very irregularly, leaving numerous tortuous cavities filled with clay, sand, or gravel. Generally the upper 10 or 20 feet consists of knobs or pinnacles of rock standing in a mass of clay. Granites, sandstones, and trap rocks are also subject to erosion, and quite irregular surfaces may result; usually, however, they are comparatively smooth and regular. Erosion cavities cause much difficulty and greatly increase the cost of stripping.

Stripping Methods.—No quarry process is more variable than stripping. The nature and depth of overburden and conditions of its removal and disposal show wide differences from quarry to quarry. Therefore, equipment and methods commonly employed are subject to similar variations, which are discussed briefly in the following paragraphs.

Hydraulic Method.—The hydraulic method, which simply involves washing the overburden away with a stream of water under pressure, is the cheapest and most effective. Conditions for its successful use are, however, somewhat exacting, the chief requirements being as follows:

1. An ample supply of water must be obtainable. An average of about 10 tons of water is needed for each ton of overburden removed. However, the same water may be used repeatedly if settling basins are provided for clarification.

2. A favorably situated waste-disposal area is essential. The best conditions exist where the soil may be washed back from the quarry face or laterally into ravines or basins where it may remain.

3. Hydraulicing is effective only where the overburden is friable enough to be washed down and carried away with a stream of water. The presence of hardpan or of numerous heavy boulders may cause great difficulty and justify the use of other methods.

The equipment required for hydraulic stripping includes a pump, a pipe line, a mounted nozzle or monitor, and possibly an additional dredging pump, together with the necessary source of power. A great advantage of the hydraulic method is the wide range of action and ease of moving from one point to another. Its adaptability for removing clay and sand from irregularly eroded surfaces is an outstanding advantage.

Fig. 1.—A rugged rock surface stripped by the hydraulic method.

Soil that could be removed only with great difficulty by other means is washed out by the stream of water directed into pockets and cavities. This means is therefore particularly adaptable for stripping limestone or marble deposits. Figure 1 shows a typical eroded limestone surface from which practically all soil has been washed away by this method.

Hydraulic stripping is a potent source of stream turbidity which may be detrimental to other interests. This drawback may be overcome by establishing wide settling basins.

The cost of hydraulic stripping is quite variable but usually very low. Costs range from less than 1 cent to 12 cents a cubic yard in quarries in different parts of the country.

Dragline Scraper or Excavator.—Where a convenient dumping ground is available a dragline scraper is effective. It lacks flexibility in lateral movement, however, unless provided with special attachments; if worked

from a derrick arm it is much more flexible, as the entire equipment is on a portable mounting, and the lateral motion of the derrick arm gives the excavator a wide range of action. Draglines have been used successfully in cleaning out large erosion cavities filled with clay.

Power Shovel.—The power shovel is the most popular type of stripping equipment. Steam and electric shovels are in common use, and compressed-air shovels are employed in a few localities. Power shovels handle material of all kinds with great facility but are not well-adapted for work on uneven rock surfaces. For removing clay from the larger erosion cavities some of the smaller types of tractor or caterpillar shovels with dippers not more than three-fourths yard in size are used. Various methods have been tested to overcome successfully the difficulty of stripping rough, eroded limestone surfaces with a power shovel. As they are encountered rock projections may be broken by blasting and set to one side or thrown over the edge of a quarry by means of the shovel dipper; better access to the soil is thus provided. Another method is to blast and load rock and soil together, but unless a washer is used clean separation later is difficult.

Costs of power-shovel stripping vary greatly according to conditions. A thick overburden of easily excavated soil on a smooth rock surface may be loaded and removed to a near-by dump for only 15 to 30 cents per cubic yard. Under average conditions the cost runs from 30 to 50 cents a cubic yard, but where loading is difficult it may be considerably higher.

Other Mechanical Equipment.—For cleaning out deep erosion cavities clamshell buckets worked from derrick arms have limited application. Small tractor excavators similar to those for road grading are also employed. Where the overburden is moved only a short distance mechanical conveyors are used. Scrapers with or without wheels, hauled by horses or mules, are employed where the overburden is too thin for successful power-shovel operation. Various methods may be combined, as, for example, a dragline scraper which dumps through a trap in a platform into cars that are hauled by locomotives.

Hand Methods.—Removal of overburden by hand methods, involving the use of picks and shovels by quarry workers, is slow and laborious. Under modern wage conditions it is also costly. Dirt loading by hand at quarry floors is often done by contract at 15 to 25 cents a cubic yard, but the dirt is loose and easily loaded. Loosening and loading undisturbed soil may cost 30 to 45 cents a cubic yard, and a haulage charge must also be added. Clay dug from deep pits and cavities by hand may require several handlings and the cost is increased proportionally.

Utilization of Overburden.—At some cement-plant quarries clay which overlies the limestone may be one of the necessary raw materials; otherwise, it is rarely used except as a filling material. In the latter capacity it may be employed to fill swamps, ravines, or other low places,

rendering such areas available for agriculture or building. Overburden may also be used for dams, roadways, or railroad grading. In rare instances clay overburden is suitable for brick.

Disposal of Overburden.—Proper disposal of material stripped from rock surfaces requires keen judgment and foresight. Desire to attain quick results at small expense and lack of foresight regarding probable extent of future operations are the chief causes of removing soil to an insufficient distance from the excavation, a common mistake in stripping. In quarrying dimension stone a large amount of waste usually is added to the pile of overburden, and in the course of years the accumulation may be very extensive. Consequently, after a few years' operation quarry owners find it necessary to handle waste a second time, augmenting greatly the expense of quarrying. If excavations are too close to spoil banks, as quarries are gradually enlarged rock slides may result; some quarries have been abandoned on this account.

As important as distance is the direction in which waste is carried. If prospecting has been adequate the direction future development must take usually can be determined. Thus, if workable beds are narrow and steeply inclined, obviously lateral development must follow the direction of strike; nevertheless, in many quarry regions waste has been piled directly over good rock that would in the natural course of events be quarried in a few years. Thus, extension of workings is impeded or made more costly.

Provision for adequate disposal of waste is therefore an important part of every quarry plan. It may, indeed, be found necessary to carry waste a considerable distance, in which event an efficient transportation system is essential. Overburden and waste are at times thrown into abandoned quarries, but before this is done an operator should be assured that permanent abandonment is fully justified.

Avoidance of Stripping by Underground Mining.—By adopting underground mining methods the stripping problem is sometimes effectively solved. An unusually heavy overburden is one of the chief incentives for undertaking excavation of rock by means of drifts and tunnels, for this method eliminates stripping costs.

GENERAL METHODS OF OPERATION

Open-pit Quarrying.—Most rock products of commerce are obtained from open quarries. Material suitable for use ordinarily is found at or near the surface of the earth, and the most economical method of working is to open up a face of the rock ledge. As rock is separated by blasting or other means, an opening is gradually enlarged and deepened, its size and shape depending greatly on the rock structures. Wide, shallow openings may be made in comparatively thin flat-lying beds, such as are common in limestone districts of the Middle West. Where beds are folded and

tilted at high angles, as in the Appalachian region of the Eastern States, open pits may be narrow and deep. Some open-pit slate quarries of Pennsylvania have reached depths of 500 to 700 feet because the desirable beds are relatively narrow and almost vertical. Also, where land values are high, and property lines restricted, or where a heavy overburden of soil or waste rock makes lateral extension expensive, quarries are likely to be narrow and deep.

There are two types of quarries, the "shelf" quarry and the "pit" quarry. Sometimes a ledge of serviceable rock stands above the level of the surrounding country, and by working into the hillside a quarry can be developed, with the floor little if any lower than the surrounding land surface. Such ready access and easy transportation are advantageous. Furthermore, drainage is usually automatic, and pumping expense is avoided. Excavations of the shelf-quarry type can usually be classed as low-cost operations.

Conditions are not always so favorable; a rock deposit may not extend above the general level, and a pit must be sunk. Access is gained by ladders, stairs, or mechanical hoists, and material is transported from the quarry by inclined tracks, derricks, cableway hoists, or other means. Such pit quarries also require pumping. Though less advantageous than shelf quarries, thousands are in regular operation. When properly designed and well-equipped they may be operated at a cost which compares favorably with that at many shelf quarries.

Underground Mining.—When quarrying of rock first was begun as an industry, excavations were made in formations readily available at the surface of the earth. Through long years of continued operation the most available outcrops were gradually worked away, and quarries reached increasing depths. Many limestone beds which provide suitable stone dip at steep angles and are of limited thickness. In following these beds down the dip greatly increasing depths of overburden are encountered. Consequently, in many localities mounting difficulties in the way of open-pit quarrying, with rising costs, have induced operators to change their systems of excavating and to develop underground mining methods. Many limestone and marble, and a few granite and slate deposits, are successfully mined underground. Selective mining can best be accomplished by the underground method, for drifts and tunnels may be confined to serviceable rock, waste and overburden being left undisturbed. As workmen are not exposed to the weather, working conditions are also more favorable.

Gloryhole Mining.—Gloryhole mining is adapted only to the production of broken stone. This method has features in common with both open-pit and underground mining, and is modified to suit varying conditions. A circular or oblong open pit is the most usual type. Rock is quarried around the sides and conveyed by dragline or other means

to a funnel-shaped opening at the center, where a chute is provided through which the rock is conducted to cars which convey it to the surface through a tunnel.

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PART II

DIMENSION STONE

CHAPTER V

GENERAL FEATURES OF DIMENSION-STONE INDUSTRIES

DEFINITION OF DIMENSION STONE

The term "dimension stone" is generally applied to masses of stone prepared for use in the form of blocks of specified shapes and usually of specified sizes. Other forms that find commercial use are designated "broken," "crushed," or "pulverized" stone. Stone fragments that are classed in the second group may be of specified sizes, the sizing usually being accomplished by screening, but the outstanding distinction between fragments of broken or crushed stone and masses of dimension stone is that the former are irregular and are in an infinite variety of forms, while the latter are cut to definite shapes such as rectangular, columnar, tabular, or wedge-shaped.

PRINCIPAL USES

Building Stone.—One of the chief uses of dimension stone is as a material of construction, but this branch of the industry contains many subdivisions. In its broader sense the term "building stone" includes stone in any form that constitutes a part of a structure; however, cut or rough-hewn blocks for exterior walls are most widely used. They may be employed only for certain parts, as for window sills, trim, cornice, base courses, chimneys, or steps.

Cut stone is employed extensively for both interior and exterior columns. The more ornamental types are utilized for interiors, as floor tiles, steps, wainscoting, fireplaces, hearths, mantels, baseboards, banisters, toilet inclosures, laundry tubs, and in various other ways. Slabs are used for flagging. Cut stone is also in demand for bridges, dams, retaining walls, docks, sea walls, lighthouses, and similar structures where strength, permanence, and resistance to shock are essential.

Building stone used in the construction of walls is of four main types—cut or finished stone, ashlar, rough building stone, and rubble. Cut or finished stone is the most costly because, for the most part, blocks are accurately shaped in accordance with detailed drawings. They may be plain rectangular blocks for uninterrupted walls or cut and carved to special shapes and designs for corners, window and door spaces, caps, or cornices. This classification includes sawed limestone and marble, finished or semifinished.

"Ashlar" is a term applied in general to small rectangular blocks of stone having sawed, planed, or rock-face surfaces, contrasted with cut blocks which are accurately sized and surface-tooled. Many types are in use. Even-course ashlar consists of blocks of uniform height for each course, although succeeding courses may be of thicker or thinner blocks. They may be of uniform or of random length. Exceptionally, end joints are slanting or irregular. Random ashlar consists of blocks

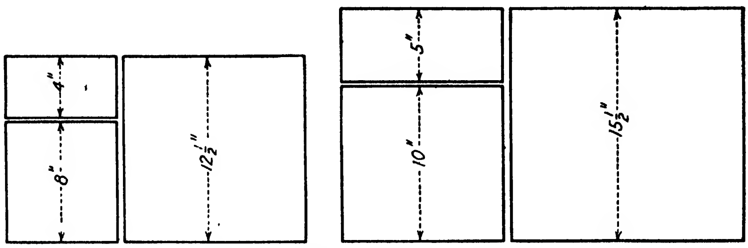

FIG. 2.— Ashlar in two-unit heights.

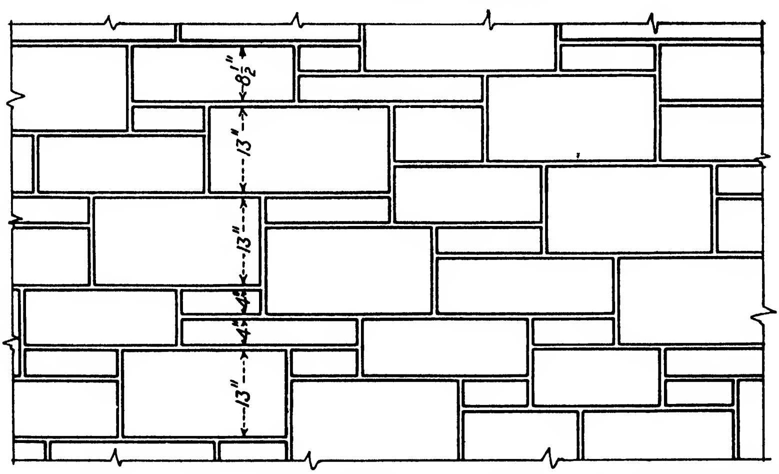

FIG. 3.—A common method of laying ashlar in three-unit heights. (*Courtesy of Indiana Limestone Company.*)

of several sizes that may be fitted together to make a wall having irregular and unequally spaced joints. Two, three, or more unit heights may be employed, as several smaller sizes may give the same height as one of the larger blocks. Thus, as shown in figure 2, the two smaller blocks with a mortar space between reach the same height as the larger block. In figure 3 the use of random ashlar in three-unit heights is shown. It may be observed from this figure that blocks which fit together properly with ½-inch motor joints must have thicknesses of 4, 8½, and 13 inches, respectively. Random ashlar not only provides builders with means of attaining remarkable variety in architectural design but permits quarry and mill operators to utilize fragments of various sizes that

might otherwise be wasted. The building of random ashlar walls is mason's work, while the setting of cut stone is a separate art.

Rough building stone consists of rock-faced masses of various shapes and sizes. Stone masons build them into walls having irregular joints. They are widely used in residential construction for chimneys, basements, or entire walls, and also to some extent for public buildings, bridges, fences, and the more ornamental types of retaining walls.

Rubble is the crudest form of building stone. The term is generally applied to irregular fragments having one good face. Such rock was once in ordinary use for basement walls, retaining walls, or similar types of construction for which concrete is now generally employed. Production of rubble has declined greatly during recent years.

Monumental Stone.—Memorials range from simple markers and headstones to elaborate and massive monuments. Usually stone that takes a good polish is requisite; in fact, the very highest types of flawless, uniform stone are used for monumental purposes. However, monuments with tooled, hammered, or even rough-hewn surfaces are not unusual, and less flawless stone may be thus employed.

No sharp line can be drawn between monumental and building stone, for monuments merge into buildings. The Washington Monument is essentially a building equipped with an elevator for passenger service, though in design and purpose it is a monument. The Lincoln Memorial, the Arlington Amphitheater, the Bok Singing Tower, and mausoleums in various parts of the country are other memorials that have many features of buildings and for which building stone is used.

Paving Stone.—One of the early uses of stone was for street and highway paving, the old Roman roads of Britain being outstanding examples. While the demands for hard-surfaced roads were not so urgent long ago as today, there was real need for something better than dirt or even broken-stone roadways, particularly for the heavy traffic of growing cities. Concrete was unknown, and blocks of native stone were the logical materials. "Cobblestones"—rounded or irregular blocks—were widely used but were gradually replaced by rectangular paving blocks with smooth, even surfaces. During recent years concrete and macadam have far outstripped paving blocks for hard-surfaced road construction, but many stone pavements still give unsurpassed service under the most severe traffic demands. They are found chiefly in railroad freight yards, around docks, and in streets traversed by many heavy drays and trucks. Paving blocks are also much in use between street-car tracks, not only because of their wearing qualities but because of the facility with which they may be taken up and replaced when track repairs are necessary.

Although the softer types of paving stones are gradually disappearing with heavy traffic increasing year by year, granite and indurated sandstone, the most resistant types, are still in wide and steady demand.

Curbing.—The manufacture of curbing is an important branch of the stone industry. Curbstones are of two types—straight and corner. Corner curbs are curved; they are more difficult to make than straight curbstones and require more material, as a considerable amount of rock is wasted in shaping them. The harder stones are more durable than concrete and on this account are particularly well-adapted for corner curbs where shocks from the wheels of traffic are exceptionally destructive.

Flagging.—Flagging is used chiefly for sidewalks and for paving courts, landings, and platforms, but the advantages of concrete for such uses have led to a rapid decline in output. In the past probably 95 per cent of the total flagstones produced were of bluestone, a variety of sandstone. Ornamental slate flagging is now used quite extensively and limestone, granite, and trap rock to a limited extent.

Miscellaneous Uses.—Stone is utilized in a multitude of minor ways that may not be included in any of the above groups. In household equipment it is found as radiator covers, table and dresser tops, lamp bases, vats, sinks, refrigerator shelves, and flour bins. Ornamental types are used for novelties, such as ink wells, paper weights, smoking sets, ash trays, clocks, and statuary. Slate is used for blackboards, bulletin boards, and billiard-table tops. Several types of stone are widely used for electrical panels and switchboards. In yards, gardens, and parks stone is employed for walks, stepping stones, statuary, fountains, bird baths, and garden seats.

REQUISITE QUALITIES OF DIMENSION STONE

General Requirements.—Although innumerable occurrences of rock are to be found throughout the world only a small part of them consist of rock that will satisfy the exacting requirements of dimension stone. Freedom from cracks and lines of weakness is essential. No deposit that has irregular or closely spaced joints is suitable, because sound blocks of moderate to large size are demanded. Uniform texture and grain size, together with a constant and attractive color, are usually required. The rock must also be free from minerals that may cause deterioration or staining.

Another important quality is the state of aggregation. If the grains are loosely coherent the rock may be described as "earthy" or "friable." Rock in which the grains adhere closely and strongly is the most desirable. However, when cementation is carried to an extreme as in the case of some quartzites, the rock is very difficult and expensive to work. Some important qualities that demand consideration are discussed in the following paragraphs.

Composition.—A rock consists of one or more minerals made up of elements combined in definite proportions, which may be determined by chemical analysis, and the minerals may be determined by visual observa-

tion with the unaided eye or with the assistance of a hand lens or microscope. Often the value of a chemical analysis of dimension stone is overemphasized, as adaptation to use depends chiefly on physical properties. At times an analysis may have value; for example, it may indicate the amount of clay in a limestone, a fact which has some bearing on its durability. Usually study with a petrographic microscope is much more effective than chemical investigation; it is also quicker and cheaper. One skilled in the use of a microscope may identify the minerals in a rock and note their state of aggregation, freshness, relative abundance, impurities, and texture and to some extent interpret the history of the rock and learn what influences have been at work to improve or impair it for structural or other uses.

Hardness and Workability.—The hardness of a rock is its resistance to abrasion and depends directly on the hardness and texture of its component minerals. Most of the constituents of granite are as hard as or harder than steel, and such rock is therefore difficult to tool. Pure limestones are soft enough to be scratched easily with a knife. Marbles are somewhat harder than limestones. The grains of a sandstone consist of quartz, which is very hard, but workability depends rather on the nature of the cementing material and its state of aggregation. A friable sandstone may be worked readily because the grains separate with ease, while a siliceous sandstone or quartzite, in which they are firmly cemented together with quartz, is very difficult to cut and dress.

Hardness has direct bearing on the workability of all rocks, yet its effect on use is quite variable. For exterior or interior walls or for decorative effects the hardness of a rock is unimportant, in so far as quality is concerned, because it is not subjected to wear. On the other hand, for floor tile or stair treads hardness is very important, as the rock is subjected to severe abrasion. It is the most essential quality of stone used for paving and curbing, for such stone must be able to resist adequately the abrasive action of heavy traffic.

Texture.—The term "texture" as applied to rock means size, degree of uniformity, and arrangement of its constituent mineral grains. In the rougher types of building stone uniformity is not required; in fact, recent architectural demands tend toward variable, uneven texture. In the more ornamental types of building and monumental stone uniform texture has vital importance.

Color.—Rocks are of many colors, and choice depends on individual taste or prevailing fashion. Choice of color in stone is influenced by location. For smoky cities white and very light colors are undesirable. Some rocks change in color with age, but this is not always objectionable. Practically all colors are in demand for monumental stone, and those rocks in which there is marked contrast between polished and tooled surfaces are preferred, for on such monuments inscriptions are

most easily read. For building stone, red, brown, buff, gray, or white rocks are widely employed. Dark-gray or black rocks are in demand only for certain special uses. The buff or yellow tints of many limestones and sandstones and the red or pink coloration of many granites are due to the presence of minute grains of iron oxides, but these are stable minerals that cause no stains. Surface stains are serious blemishes and are generally due to the presence of small grains of pyrite, marcasite, or siderite which oxidize by weathering. Stains sometimes are caused by cementing materials used in setting the stone.

Strength.—Rock is a very strong material. Structural stone that is sound and suitable in other respects is almost invariably strong enough for any use. Bridge piers, arches, and the bases of tall monuments must sustain great pressure, but even in such structures the strength of ordinary stone far exceeds the requirements of safety. The pressure on the base course of the Washington Monument is less than 700 pounds a square inch; and high-grade granites, limestones, and marbles will sustain a crushing load of 10,000 to 25,000 pounds a square inch. Recent tests at the United States Bureau of Standards on samples of Montana quartzite indicated the remarkably high compressive strength of 63,000 pounds a square inch. A structure of such material would have to be over 10 miles high before failure would occur from crushing of the lower courses. It is, however, generally conceded that rock disintegrates and tends to weaken more readily when under severe stress; therefore a factor of safety of 20 is usually demanded—that is, stone must be able to resist a crushing stress twenty times as great as that to which it will be subjected when placed in a wall. For ordinary uses, a stone that will sustain a crushing strength of 5,000 pounds to the square inch is considered satisfactory.

Tests of transverse strength—strength required to sustain a load applied at the middle of a bar of stone supported at the ends—are more important than crushing-strength tests, for they show the adaptability of the stone for use as window and door caps.

Porosity.—Pore space or porosity, expressed as the percentage of pore space to the total rock volume, is quite variable in different types of rock. Sandstones may have a porosity of .1 to 10 per cent. Commercial limestones range from less than 0.5 to 5 per cent. Marbles, granites, and slates are usually of very low porosity, many of them less than one-tenth of 1 per cent. Porosity affects the durability of stone by permitting infiltration of water which may contain solvents, or which may freeze in the pores. Early writers have stated that danger from frost action is directly proportional to the percentage of pore space, but Buckley[2] has pointed out that the important factor to consider is the facility with which

[2] Buckley, E. R., The Building and Ornamental Stones of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey Bull. 4, Econ. Ser. 2, 1898, p. 22.

the stone gives up water. Rocks having pores of subcapillary size give up their included water much more slowly than those with larger pores, therefore those with fine pores suffer most seriously from frost action. Parks[3] determined the permeability of many rocks and found that it bore no relation to the percentage of porosity or to the effect of frost. It is apparent, however, that the solvent effect will be greater in rocks of greater permeability. The extent to which a stone will take up water is usually expressed as ratio of absorption, which is the proportion of the weight of absorbed water to the weight of the dry sample.

Specific Gravity and Weight per Cubic Foot.—The specific gravity of a stone is its weight compared with the weight of an equal volume of water. It may be expressed in two ways—as "apparent" or as "true" specific gravity. Apparent specific gravity is that obtained when pore spaces are filled with air throughout the determination. True specific gravity is obtained when pore spaces are eliminated, either by so completely saturating the rock that they are filled with water or by using finely ground rock powder in making the determination.

The specific gravity of common rocks ranges from 2.2 to 2.8 and the weight per cubic foot from 140 to 180 pounds, depending upon the weight and relative abundance of the constituent minerals and upon the porosity.

Data on Physical Properties.—Merrill[4] presents numerous tables showing specific gravity, strength, weight per cubic foot, ratio of absorption, chemical composition, and other properties of many building stones. Since that book was written many thousands of tests have been made and the results recorded. The United States Bureau of Standards has made the most noteworthy contributions to our knowledge of the physical properties of building stones. Publications[5] covering marbles, limestones, and slates are now available. Dale's various reports on marble, granite, and slate as recorded in the bibliographies of the respective chapters in this volume, also contain a great deal of physical test data. Numerous textbooks and State reports also present tables or incidental information on crushing and transverse strength, ratio of absorption, weight, and other physical properties of stones from innumerable specific localities. A compilation of this great mass of data would constitute

[3] Parks, W. A., Report on the Building and Ornamental Stones of Canada. Canada Dept. Mines, vol. 1, pt. 1, 1912, p. 62.

[4] Merrill, G. P., Stones for Building and Decoration. 3d ed., John Wiley & Sons, Inc., New York, 1910, pp. 497–579.

[5] Kessler, D. W., Physical and Chemical Tests on the Commercial Marbles of the United States. U. S. Bur. of Standards Tech. Paper 123, 1919, 54 pp.

Kessler, D. W. and Sligh, W. H., Physical Properties of the Principal Commercial Limestones Used for Building Construction in the United States. U. S. Bur. of Standards Tech. Paper 349, 1927, 94 pp.

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a book in itself, and lack of space forbids its presentation herein. Therefore, the reader who desires knowledge of the qualities of stones from certain locations is referred to the texts mentioned in the footnotes or given in the appropriate bibliographies.

Durability.—Climate has a very definite bearing on the durability of stone. Cleopatra's Needle, a column of granite which was transported to New York and set up in Central Park, is said to have suffered more from exposure during a score of winters in the climate of America than during the centuries it stood in the mild, uniform climate of Egypt. Probably incipient decay had begun before its removal, and the severe climate of this country speedily made the deterioration apparent.

Most standard commercial types of building and ornamental stones are sufficiently durable for ordinary use. By examining the effects of weathering on outcrops that have long been exposed to the elements in undeveloped deposits the durability of rock may be judged, or where stone has been quarried for many years observations may be made on old structures in which it was used. In this respect America does not have the advantages of the Old World, for even our oldest buildings are comparatively new when considered on the basis of the life of high-grade stone.

Durability of stone is now tested quite extensively in laboratories, chiefly by means of accelerated freezing and thawing tests and by accelerated acid tests. Resistance to fire is an important consideration. It has been found that limestones withstand the effects of fire up to the point of calcination better than other stones. Next in order are sandstones, fine-grained crystalline rocks, and the coarser crystalline rocks. As a rule, the finer grained and more compact the stone and the simpler its mineral composition the better it will resist damaging effects of extreme heat or the spalling effects that result from rapid cooling when water is applied.

More detailed requirements for specific uses will be included under the discussion of each commodity.

ADAPTATIONS OF RAW MATERIAL TO USE

Stone is employed in many different ways. Obviously the requirements of use are variable. Stone products differ from synthetic compounds in that the composition and properties of the latter can within certain limits be changed at will, whereas the composition and physical character of stone remain exactly the same in the finished material as in the solid rock ledge. Man can fashion rock into any desired size or shape and can polish or otherwise finish the surface, but he is powerless to change in the slightest degree the texture, inherent color, hardness, or proportion or character of constituent minerals. He has, however, the power of selection, and this must be exercised with great care. The

stoneworker must study his material, be familiar with its properties, and understand the requirements of use. He is thus enabled to judge the possibilities of a rock deposit and its adaptations. Some rocks are eminently fitted for monumental uses, some for building, and others for interior decoration.

COMPLEXITIES IN MARKETING

Some quarrymen simplify their marketing problems by selling products in rough-block form to dealers or manufacturers. Rough blocks, however, command a much lower price than finished products, and the desire for larger incomes and increased profits has led many operators to establish mills of their own. If structural stone is manufactured marketing may become complex. Some quarries specialize in one product, the marketing of which may be simple. While, as previously shown, diversification has its advantages, marketing becomes more complex because the various products may enter entirely different fields of utilization. Large quantities of granite, limestone, and sandstone are sold as rough blocks to independent mills, but slate is usually manufactured in plants directly associated with quarries.

ROYALTIES

Stone deposits are sometimes owned by one individual or company and operated by an independent concern. Such properties are usually worked on a royalty basis. Factors to be considered for the most reasonable determination of royalty are the value of the deposit and the quantity of commercially available material therein. Thus a fair market value for the property, divided by the number of tons or number of cubic feet of rock available, will give a fair figure for royalty.

The value of rock in the ground is commonly overestimated, for it really constitutes only a small part of the selling price of the finished product. A fair market value is often difficult to determine. It may be defined as the value agreed upon between a willing seller and a prudent purchaser, both of whom have enlightened understanding of the commodity involved.

Royalty is commonly expressed as a percentage of the selling price at the mine or quarry. According to the Leasing Act of June 30, 1919, as amended December 16, 1926, a minimum royalty of 5 per cent of the net value of the output at the mine is charged for minerals taken from Government lands. The royalty may exceed 5 per cent, the exact figure being determined from a review of all the circumstances surrounding each individual commodity or deposit.

Whatever the basis of determination, royalty is usually charged as so much a ton or cubic foot of material sold. Royalties vary considerably depending upon size of operation, value of product, and other factors. In

the Atlanta (Ga.) district, a royalty of 25 cents a cubic foot of block granite and 2 to 5 cents a cubic foot of granite curbing is customary. For Indiana limestone sold as cut stone, commanding a price of \$2 or \$3 a cubic foot, royalties ordinarily range from 4 to 10 cents a cubic foot. If the limestone is sold as rough building stone the royalty is lower and may be 2 to 5 cents a cubic foot. Royalties on slate are commonly about 10 per cent of the net selling price. A minimum average daily or monthly production is usually a condition of a royalty agreement.

CHAPTER VI

LIMESTONE

DEFINITION

Limestone is a rock consisting essentially of calcium carbonate ($CaCO_3$), the mineral calcite. Rocks classed commercially as limestones may contain varying quantities of magnesium carbonate; when 10 per cent or more is present they are termed "magnesian" or "dolomitic" limestones; if the amount approaches 45 per cent the rock is composed essentially of the double carbonate of lime and magnesia ($CaCO_3$, $MgCO_3$), the mineral dolomite. When used as dimension stone dolomite is classed commercially as limestone.

ORIGIN

As pointed out in a preceding discussion of sedimentary rocks, limestones have originated chiefly from calcareous organic remains, supplemented to some extent by chemical precipitation. Only those limestones that have been firmly consolidated have importance as dimension stone.

PHYSICAL PROPERTIES

Limestones vary greatly in physical characteristics. Hardness depends on the degree of consolidation as well as on the actual hardness of the component minerals, but even the densest forms of limestone can be easily scratched with a knife. They range from pure white to black, the color effects being brought about chiefly by impurities. In texture they may be amorphous, semicrystalline, or crystalline. They vary in compactness from loosely consolidated marls through the denser chalks to compact normal limestones and the harder marbles. The less-compact limestones have the higher degree of porosity and may weigh as little as 110 pounds per cubic foot, whereas the more compact varieties may weigh 150 to 170 pounds. For most uses dense, highly consolidated forms are preferred.

VARIETIES

Limestones are classified according to the nature of their impurities. "Siliceous" or "cherty" limestone contains considerable silica and "argillaceous" limestone clay or shale. The so-called "cement rock," which is widely used for cement manufacture in the Lehigh Valley district of Pennsylvania, is a good example of the latter. A "ferruginous"

limestone contains iron, which usually gives rock a buff, reddish, or yellowish color; the "carbonaceous" or "bituminous" type contains carbonaceous matter, such as peat or other organic materials.

Another series of names is applied to limestones, according to their texture, state of aggregation, or appearance. "Common compact" limestone, the most widespread type, consists of a fine-grained, dense, homogeneous aggregate ranging from light gray to almost black. "Lithographic" limestone is an extremely fine-grained, uniform, crystalline, magnesian variety, usually drab or yellowish. As its surface can be etched with weak acid, it may be employed for lithographic printing. "Oolitic" limestone, so-called because of its resemblance to fish roe, is composed of small rounded grains of lime carbonate of concentrically laminated structure. When the grains approach the size of a pea the rock is called "pisolite."

Limestone is composed primarily of shells of ancient sea animals. Usually they have been comminuted so completely that no trace of organic structure remains. Some beds, however, have been formed under conditions that have left the shells almost intact or at least in fragments well preserved enough to indicate their character and origin; these are known as "fossiliferous" limestones. Some are made up almost entirely of shells of one kind and are named accordingly. "Coral," "crinoid," and "coquina" are common types. "Chalk" is a fine-grained, white, friable limestone composed largely of minute shells of foraminifera. In places, oyster-shell beds are quite extensive in area and thickness and are more or less firmly consolidated; therefore, they may be regarded as shell limestones of very recent origin.

"Travertine" is a variety of limestone that is regarded as a product of chemical precipitation from hot springs. As it is deposited in successive layers and as chemical composition and conditions of deposition may vary during this process, a banded structure commonly results. The rock is characterized by the presence of numerous irregular cavities ranging from the size of a pin's head or smaller to one-half inch or more across. Some porous limestones are classed commercially as travertines, though they differ from them in origin. Some travertines will take a fair polish, but most of them are used with a sand-rubbed finish and therefore are classed as limestones rather than marbles. Travertine is used principally for interior walls, decorative effects, floor tile, and steps. Some varieties are remarkably resistant to wear. Use as a flooring material in the concourse of the Grand Central Station in New York is a good illustration of the adaptability of travertine for service where abrasion is constant and intense. Artificial travertines—synthetic products—are sold as substitutes, but they have neither the wearing nor the decorative qualities of true travertine. "Tufa" is a name applied to a cellular calcareous deposit originating from mineral springs.

Another form of calcium carbonate is precipitated from cold-water solutions in limestone caves and forms many ornate structures, such as stalactites and stalagmites. It is incorrectly called "onyx," although the more descriptive term "Mexican onyx" or "onyx marble" is often applied to distinguish it from true onyx, a form of silica. As Mexican onyx will take a polish and is highly ornamental it is classed with marble rather than with limestone.

QUALITIES ON WHICH USE DEPENDS

Although innumerable deposits of limestone are to be found throughout the country, only a small part of the rock will satisfy the exacting requirements of dimension stone. Sound rock, free from deleterious impurities and providing blocks of adequate size, is essential. Uniformity of texture, grain size, and color is usually required.

Purity is not regarded as an essential property of building limestone, but chemical composition may have some bearing on quality. Silica may make the stone more difficult to work. The appearance of sulphur in an analysis usually indicates the presence of pyrite or marcasite, minerals that may cause stains. Objectionable impurities are recognized generally more easily by means of a microscope or a hand lens than by a chemical analysis. Waste-stone by-products from relatively pure deposits are more easily marketed than impure by-products.

Hardness and workability are important qualities. Limestones are worked with comparative ease unless flint or other siliceous minerals are present. Hardness has a direct bearing on the workability of limestone, but its effect on use has minor importance, because limestones are used where they are subjected to abrasion only to a limited extent.

Limestones are of many colors. Brown, buff, gray, or white varieties are widely employed for building purposes, while the dark-gray or black are in demand only for certain uses. Buff or yellow coloring is due to minute grains of iron oxides—stable minerals that cause no stains. Surface stains may result from oxidation of the iron sulphides or carbonates sometimes present.

Sound structural limestone which is suitable in other respects is usually strong enough for any use. Even for bridge piers, arches, and tall monuments the strength of standard high-quality limestone far exceeds the requirements of safety.

Pore space is variable; in most commercial limestone it ranges from less than 0.5 to 5 per cent, though occasionally is much higher.

Appearance depends chiefly on color and texture. Blue limestones may change to buff by oxidation of the iron. Generally, however, permanence of color is preferred. Although uniform texture is usually desired for the more ornamental stones, variations in both texture and

color are now much in demand for sawed and rock-faced stone used in domestic construction.

USES

Limestone in the form of dimension stone is used principally in building. Its very limited application for monuments, curbing, and flagging may almost be disregarded. The largest amount is employed in the form of cut or rough-hewn blocks for exterior walls, either for entire structures or for certain parts, such as window sills, caps, cornice, or base course. Columns and balusters of the more ornamental types are widely utilized for both interior and exterior building. Limestone is also employed extensively for interior structural uses and decorative effects. Massive blocks of cut limestone are used for bridges, dams, docks, sea walls, and similar structures where strength, permanence, and resistance to shock are essential.

Limestone for the construction of walls is of four main types—cut or finished stone, ashlar, rough building stone, and rubble. The significance of these terms is fully covered in a discussion of the general features of dimension stone on pages 23 to 25. Limestone is being used increasingly as ashlar, rough building stone, and rubble. The denser, harder varieties are used for street curbing and to a smaller extent for flagging and paving.

Production of dimension limestone by uses for a series of years is shown in the following table:

DIMENSION LIMESTONE SOLD BY PRODUCERS IN THE UNITED STATES, 1925–1937, BY USES

Year	Building stone		Curbing, flagging, and paving		Rubble		Total value
	Cubic feet	Value	Cubic feet	Value	Short tons	Value	
1925	15,983,800	$16,092,079	129,730	$ 98,587	324,630	$513,387	$16,704,053
1926	18,537,950	20,391,597	167,780	135,882	254,240	476,545	21,004,024
1927	17,340,690	18,820,045	223,370	134,360	226,280	400,790	19,355,195
1928	17,641,370	20,193,963	322,560	205,724	365,920	705,723	21,105,410
1929	17,864,700	20,649,257	471,880	158,266	352,480	693,678	21,501,201
1930	15,682,720	18,535,293	346,040	137,801	756,470	623,100	19,296,194
1931	11,706,840	10,858,697	166,260	85,175	229,510	296,426	11,240,298
1932	7,414,130	7,028,224	122,000	38,332	84,570	84,308	7,150,864
1933	6,599,250	6,416,223	78,610	32,134	79,060	94,046	6,542,403
1934	5,176,860	3,391,455	116,610	49,886	190,080	179,791	3,621,132
1935	6,871,320	2,700,747	93,700	44,229	185,790	276,569	3,021,545
1936	7,735,520	4,662,716	178,000	74,053	204,700	181,415	4,918,184
1937	7,736,140	5,096,535	167,950	76,806	107,550	136,028	5,309,369

INDUSTRY BY STATES

Limestones occur in every State; but, except in widely scattered localities in about one-half of the States, they are either unsuitable for use, or conditions have been unfavorable for their development as sources of dimension stone. The more important producing centers are briefly described alphabetically by States in the following section. No attempt is made to cover undeveloped deposits or to include all that are or have been worked on a small scale.

Alabama.—The Bangor oolitic limestone of Palaeozoic age occurs in Franklin County, northwestern Alabama. The deposit extends from Newberg to Belgreen, about 20 miles, and has an average thickness of 20 to 25 feet, though it is much thicker in places. The best occurrences are near Rockwood and Russellville. The rock is a characteristic oolitic limestone similar to the extensive deposits near Bedford, Ind. Most of it is of uniform texture, though some is distinctly veined. It grades in color from light- and medium-gray to buff and is somewhat harder than Indiana limestone. Many quarry openings have been made, and since 1924 production has increased notably. Recent developments are chiefly near Rockwood, where a large stone-finishing mill is in operation. Here quarrying is conducted with the most modern equipment, and the mill is provided with all conveniences for rapid and skillful fabrication. The easy workability of the stone gives the product a wide market range; large contracts have been filled, even for cities as far north as Montreal, Canada. The technique of quarrying and manufacture is covered in a later section of this chapter, for while most of the discussion on this subject applies to Indiana, much of it will apply equally to Alabama.

Colorado.—A sandy limestone of Cambrian age, occurring near Manitou, El Paso County, is marketed under the trade name "Manitou Green-Stone." The body color is reddish brown, on which is imposed an attractive green mottling. Calcium and magnesium carbonates constitute about half the rock, the remainder consisting chiefly of quartz, with a minor percentage of iron oxide. The green color is attributed to the presence of glauconite or a related mineral. Quarry conditions are favorable, as the rock occurs in easily separable beds having a maximum thickness of about 2 feet. Tests by the Colorado Geological Survey indicate that it is strong and durable. Active development of this very attractive building stone began in 1930. Colorado travertine is discussed on page 44.

Florida.—The coquina or shell limestone of Florida is probably the first building stone used in America. It consists of stratified shell fragments cemented together with finely divided calcium carbonate derived from abrasion and comminution of the shells, and it is soft enough to be cut easily with a handsaw. Although too porous for exterior use in

northern climates it appears to be quite enduring in the Florida climate. Experiments are being conducted in search of a practical method of hardening the stone and reducing its porosity to make it suitable for use in climates subject to severe frost action.

It occurs in a belt about 200 yards wide on Anastasia Island and was first quarried about 1580 to supply blocks of stone for building at St. Augustine the famous Fort San Marco (the present Fort Marion), which required many years for its construction. Though soft and porous the fort walls were remarkably resistant to gun fire. St. Augustine is called "the coquina city," because so much of this material has been used for buildings. There has been little recent production in this district, but a similar coquina limestone is quarried near Volusia, Volusia County. At Islamorada on Windly's Island, Monroe County, a considerable quantity of limestone is quarried and sold as cut and sawed stone and as flagging. The Tampa limestone, occurring at New Port Richey, Pinellas County, is quarried to some extent for building purposes. In places it is porous, like travertine, and is said to be very pure, containing about 98 per cent of calcium carbonate.

A soft limestone deposit at Marianna, Jackson County, in northern Florida is known locally as "chimney rock." Many years ago it was quarried in a small way and sawed into slabs when first taken from the ledge. The blocks or slabs became quite hard after seasoning and were used for making chimneys, house supports, or entire houses.

Florida travertine is referred to on page 44.

Illinois.—At times building limestone is quarried near Quincy, Adams County; at Alton, Madison County; and at Joliet, Will County. In the last locality the rock occurs in flat-lying homogeneous beds 6 to 30 inches thick. It is a fine-grained, light-drab stone which upon exposure becomes buff by oxidation of the small iron content. Large blocks are obtainable. Production in the State is small, and practically all of it is for rough construction.

Indiana.—Indiana limestone, also called Bedford limestone, Bedford oolitic limestone, and Indiana oolite, is one of the most widely known building stones. Figures compiled from returns of individual companies to the United States Bureau of Mines show that, exclusive of a small amount of stone sold for rough construction, data for which are not available, and also exclusive of rubble, Indiana in 1930 produced 12,702,980 cubic feet of dimension limestone valued at $16,186,172, or more than 81 per cent of the total quantity and 87 per cent of the total value for the United States. Corresponding figures for 1931 were 7,874,470 cubic feet valued at $8,595,612, and for 1937, 4,442,360 cubic feet valued at $3,529,420. More than twenty large companies operate thirty to forty quarries and mills. About a dozen more operate only finishing mills. The value of finished products from independent mills is not included in the total

value. Its easy workability, adaptability for carving, attractive appearance, endurance, and abundant supply have given to Indiana limestone nationwide popularity. Chief production is in the Bedford-Bloomington district in Lawrence and Monroe Counties, but building limestone is also quarried at St. Paul, Decatur County, and at Romona, Owen County.

Structural Features.—Bedford oolitic limestone, known geologically as the Salem limestone, is of Subcarboniferous (lower Carboniferous) age. It rests on the Harrodsburg limestone and is overlain by the Mitchell limestone. All the formations are tilted gently a little south of west, with a dip of 34 to 70 feet per mile. Thus, in following the formations westward they are found at gradually increasing depths beneath the surface. In the eastern part of the area quarries are on the hilltops; in the west part, in the valleys.

The Salem limestone occurs in a massive bed 25 to nearly 100 feet thick. In Indiana it extends from near New Albany on the Ohio River northward through Salem, Bedford, and Bloomington to a point north of Greencastle, a distance of about 125 miles. Active quarrying is confined chiefly to the central part of the belt, from Bedford at the south to a few miles beyond Bloomington at the north.

The rock has little tendency to split along bedding planes. Its freedom from cleavage is a great advantage in carving, as corners and projections are not liable to split off. Cross-bedding occurs in places. Joints generally appear in two systems, the major having a general east and west direction, with minor joints north and south. As joints are spaced 20 to 40 feet apart in most places large, sound blocks are easily obtained.

The rock is remarkably free from ordinary bedding or lamination planes; however, unusual types known as "suture joints," "crowfoot," "toe nails," or "stylolites" occur in many places. They appear on the quarry face as dark-gray to black jagged lines in zones a fraction of an inch to several inches wide. The dark material is mainly organic matter or chlorite, and the peculiar zigzag form is attributed to differential solution under pressure. Some of the thicker stylolites tend to weather rapidly at the exposed face but are not generally detrimental to quality or strength. "Crowfoot" rock, sold under the classification "Old Gothic," is preferred for certain architectural effects.

Bedford stone is described as oolitic because of its resemblance to fish roe. The small, spherical grains or oolites are regarded as having originated from chemical precipitation of calcium carbonate in sea water. Usually small grains of sand or shell fragments form nuclei of the spherical masses, and, if crystalline, the calcium carbonate deposited about them may be radial or concentric. True oolites are not so numerous in Indiana stone as one would expect from the name, as most of the grains are simply shell fragments of foraminifera or other marine animals. What is known

as select stone is fine-grained (less than 1/24 inch in diameter), though medium-grained (1/24 to 1/8 inch) and coarse-grained (more than 1/8 inch) are also popular.

A "rift," or direction of easy splitting, is present in most Indiana quarries. In places it is horizontal but more generally is inclined north or south at a low angle and probably is due to crossbedding.

Color.—Indiana limestone is divided into two general color classifications, buff and gray. The buff color is regarded as a result of slow oxidation of the small iron content, because the gray to bluish-gray stone is generally found below ground-water level and the buff above. It is a curious fact, however, that uniform gradation from blue to buff is rarely seen; the boundary is usually sharp and distinct. The buff stone appears in various shades, which in general are divided into dark and light buff. Variegated rock is a mixture of buff and gray in the same block, though weathering processes gradually blend the colors until little or no difference is observable. Variegated stone is preferred for the contrasted color effects desired in modern architecture.

Hardness and Workability.—When first quarried Indiana limestone is comparatively soft and is easily worked but when thoroughly dried it is somewhat harder. Consisting as it does of an aggregation of rounded grains, it has certain working qualities that are among its most admirable characteristics. It can be readily planed, turned, or carved into any desired form and is therefore well adapted for any type of architectural design. It can be tooled so rapidly that it has an advantage in cost of manufacture over almost all other stones.

Durability.—The statement is sometimes made that, because it is slowly soluble in water containing carbon dioxide gas, limestone is not to be classed with the durable rocks. Loughlin[6] has pointed out, however, that carbon dioxide gas, even in a humid atmosphere, has no corrosive effect on limestone and that when dissolved in water it exerts a solvent action so slow that under ordinary weathering conditions it would require 450 years for this solution alone to corrode the surface two-fifths of an inch. Limestone, therefore, may be regarded as durable enough for all ordinary uses.

Generally the heavier stone is the more durable because it is more firmly cemented and less porous than varieties that are comparatively light in weight. Weight per cubic foot may therefore be regarded as an index of its durability. The average specific gravity is 2.3, and the average weight per cubic foot about 144 pounds.

Most standard building limestones are unaffected by frost after they are properly seasoned, but unseasoned stone is subject to damage;

[6] Loughlin, G. F., Indiana Oolitic Limestone; Relation of Its Natural Features to Its Commercial Grading. Contributions to Economic Geology, 1929, pt. 1, U. S. Geol. Survey Bull. 811, 1929, p. 113.

therefore quarry blocks should be exposed, with access of air to all surfaces, for 1 to 2 months before heavy frost. Quarrying is discontinued during the winter because of the damage that would result from the freezing of freshly quarried stone.

Grades of Stone.—Loughlin,[7] working in cooperation with Indiana producers, has devised the following classification:

Buff; AA, statuary; unusually fine, uniform grained. A, select; fine, uniform grained. B, standard; prevailingly medium grained with rather distinct bedding. C, rustic; prevailing coarse grained. Gray; D, E, EE, correspond to grades A, B, and C of buff stone. Variegated (buff and gray in a single block): F, variegated statuary, corresponding to AA; G, variegated, corresponding to B and C. Special grades: Hard, "Indiana travertine," very coarse grained with many large shell holes; "old Gothic," or stone of any color or grade, with or without "crowfeet" or other features that would exclude it from regular grades; "short length" stone equal in quality to the regular grades but in blocks smaller than those usually sent to stone mills.

A limited supply of rock classed as Indiana travertine is available. Although fine-grained stone is desirable, too rigid insistence on this grade would work a hardship on the industry, as it would cause excessive waste of other grades that must be quarried at the same time, necessitating a higher price and automatically limiting the market range. The coarser grained stone is equally as good as the fine; consequently the grading is not excessively rigid, and a moderate tolerance is allowed.

Extent of Supply.—The occurrences of Salem limestone are very extensive, but quarrying is necessarily confined to a zone near the outcrop as the removal of more than 40 to 60 feet of overburden would be unprofitable. Even in this comparatively narrow zone the supply of rock will be abundant for many years. Naturally the supply of buff stone is more limited than that of blue-gray. Although certain local areas may be nearly exhausted, new deposits are constantly being uncovered.

Prospecting in Indiana.—As the quality of stone varies from point to point, careful prospecting is necessary before development work can be undertaken. The essential features, such as color, grain size, and extent of beds, can be determined from drill cores. Because the beds are almost flat lying and changes in texture and color are gradual, prospect holes may be spaced 100 to 300 feet apart, although some operators prefer closer spacing. A log of the thickness, color, and texture of the limestone found in each drill hole is kept.

Kansas.—A light-cream limestone has been quarried quite extensively near Silverdale, Cowley County and white limestone suitable for cutstone trim near Manhattan, Riley County. Other production in the State is chiefly for local rough construction.

[7] Work cited, p. 114.

Kentucky.—The most widely known building stone of Kentucky is the oolitic limestone of Warren County quarried near Bowling Green. The rock is similar to Indiana limestone in color, texture, composition, and durability. It occurs in sound beds 10 to 20 feet thick; and, although it is notably uniform in composition, care must be taken in selection to avoid small pyrite lenses that may cause stains on exposure to the weather. A peculiar feature is the presence of bituminous matter which gives the freshly quarried stone a displeasing coloration, but which evaporates rapidly upon exposure, leaving a clean cream-white to light-gray surface. Quite a number of quarries have been worked at various times, but only two companies have produced building stone during recent years. Rough blocks are shipped to Bowling Green for manufacture into finished products. The stone has been used in many large buildings throughout the Middle Western and Southern States and is employed to some extent for monuments.

Maryland.—Dolomite quarried near Mount Washington at the northern edge of Baltimore is used at times for rough construction in and near the city. A deposit of attractive gray limestone near Texas, Baltimore County, is also quarried for building purposes.

Minnesota.—Dolomitic limestones ranging from nearly pure white to yellow or buff, occur in flat-lying beds in southeastern Minnesota. Certain beds, notably at Mankato, are blue when first quarried but turn buff on exposure, probably from oxidation of the iron originally present as carbonate.

The chief producing centers are Mankato, Blue Earth County; Kasota, Le Sueur County; Mantorville, Dodge County; and Winona, Winona County. The stone at Mankato and Kasota is strong, attractive, and obtainable in large blocks; it is well-adapted for construction of heavy masonry and bridges. The chief commercial beds at Kasota are recrystallized to such an extent that the material will take a polish and is therefore sometimes classed as marble rather than limestone. Yellow and pink Kasota stones are popular for interior decoration. A gray to white attractive and durable building stone is obtained high on the river bluffs near Winona. In some ledges the stone is porous and is marketed as travertine.

Missouri.—Stone quarried at Carthage and Phoenix is classed as marble and is described in the marble chapter.

New York.—Limestones for building, both dressed stone and rubble, are quarried near Syracuse, Onondaga County. A small amount is produced elsewhere, chiefly for local rough construction.

Pennsylvania.—There are many important deposits of limestone in Pennsylvania, but they are used very little for building purposes. Beds that should furnish the best building stone are situated in the southeastern part of the State where geological forces have folded and shattered

them excessively. Cambrian and Ordovician limestones of Northampton, Lehigh, and Berks Counties were used for foundations and house building many years ago. The rock is available only in small blocks but apparently is quite durable. The date 1821 appears in the gable of a limestone house about 4 miles north of Easton, Pa., and the building apparently is still in excellent condition. Limestones of Cumberland, Franklin, and Montgomery Counties have been used locally for dwellings and arched bridges. Local limestone was used in the construction in 1766 of the Harris Mansion, the oldest house in Harrisburg, and also for the Paxtang Church just east of that place built in 1740. Pennsylvania limestones evidently have an interesting history, but they are used very little at present. Limestones now produced in Pennsylvania are classed chiefly as rough construction stone, and the annual value of the output is $25,000 to $100,000.

Texas.—Texas limestone quarrying has exhibited increasing activity during recent years. At Cedar Park, Williamson County, a ledge about 30 feet thick provides a pale-buff to cream oolitic limestone of even texture, well adapted for carving. Certain beds contain large fossils and are porous, resembling travertine. Large shipments of building stone are made from these quarries.

At Lueders, Jones County, a deposit of thin-bedded, light-gray and variegated limestone covering a wide area has been quarried quite extensively. Three beds—8 inches, 1 foot 5 inches, and 1 foot 10 inches thick, respectively—are separated by loose beds about 2 inches thick. Therefore, no channeling machines are required, as the rock is easily removed by drilling and wedging.

Near Del Rio, Kinney County, a 15- to 30-foot ledge in layers 2 to 4 feet thick has been quarried over an area of 5 or 6 acres. The stone is harder and less uniform than that quarried at Cedar Park.

Utah.—A fine-grained, light-colored, oolitic limestone is quarried near Ephraim, San Pete County, and used as building stone in Salt Lake City and Provo. Some has been shipped to San Francisco.

Wisconsin.—Limestone of Niagara age is quarried at Wauwatosa, Milwaukee County. It is light gray, with variations to white and buff. Two types are procured, a finely crystalline compact limestone and one of coarse granular texture in heavy beds. The chief market is in Milwaukee, where the stone has been used for bridges, ashlar, footings, sills, and rubble.

A thin-bedded, hard, gray dolomite, exceptionally strong and durable, occurring near Lannon, Waukesha County, has been used quite extensively for curbing and flagging; some is employed also as building stone.

OCCURRENCES OF TRAVERTINE

Travertine has not been produced extensively in the United States, although sales have been recorded from a few States during recent years.

Some porous limestones sold commercially under this classification are not true travertines.

A quarry near Bridgeport, Mono County, Calif., which, many years ago, furnished what was regarded as marble for buildings in San Francisco, was again operated in 1929. The stone comes in a variety of colors; some of it, ranging from clear white to pale yellow and gray, is said to be of the same texture and quality as the best Roman travertine. It is also obtainable in orange, pink, red, and brown.

A deposit that compares favorably with the famous Italian travertine has been developed about 6 miles east of Salida, Colo., close to the Denver & Rio Grande Western Railway. The deposit forms one side of a hill rising 250 feet from the valley floor and is worked as a shelf quarry conveniently situated for waste disposal and with automatic drainage. The exposure is 1,300 feet long and 200 feet thick. Joints are spaced so widely that blocks large enough for monolithic columns are obtainable. The rock is said to have a compressive strength of 12,000 to 14,000 pounds a square inch and on account of its porosity weighs only 135 pounds a cubic foot. It is light buff, is very attractive, and is being used widely in Denver and other cities for both interior and exterior building.

Two other travertine quarries have been opened recently in Colorado, one near Salida, Chaffee County, and one near Canon City, Fremont County. Up to 1931 production was confined to terrazzo.

In 1932 production of travertine was begun at Gardiner, Mont., near the north entrance to Yellowstone National Park. As the material occurs in a variety of ornamental colors and is adapted for polishing, possibly it should be classed as onyx marble. Several carloads have been shipped to St. Paul, Minn., for sawing and finishing. Travertine also occurs west of Landusky, Phillips County, Mont.

A deposit of rock well-adapted for architectural use has been worked near Bradenton, Fla. The stone exhibits the characteristic porous texture of Italian travertine and resembles it in general appearance. Production has been recorded since 1929, some of the material being sold under the trade name "Floridene" stone.

A travertine quarry was operated for a brief period near Cuthbert, southwestern Georgia. The rock is brown to golden and of porous structure. Limited amounts were sold for interior building and waste material was marketed as chips for terrazzo floors.

The output of certain porous beds in the limestone bluffs near Winona, Minn., is sold as travertine, though most of the limestone in this district is massive and compact. Similarly, exceptional beds resembling travertine occur in the Indiana limestone deposits, but very little is marketed. An attractive porous limestone is quarried near Cedar Park, Tex.

QUARRY METHODS

Quarry Plan.—Most deposits of limestone used as dimension stone are approximately flat lying and of limited thickness. Thus, the stone available in any one opening may be removed within a short time and a new ledge uncovered. The abandoned pits may therefore be utilized for disposal of waste and overburden from succeeding benches.

In Indiana, where a greater part of the building limestone is produced, most ledges are 120 to 140 feet in width to permit service by a derrick boom; sometimes blocks from the most remote parts of the ledge must be dragged. At large quarries a series of derricks is set in line and a long ledge worked down in a succession of floors until all the good stone is removed. The line of derricks is then moved back 120 to 140 feet and another ledge begun. Stripping and waste from the last operation are thrown into the opening previously made; thus, a wide area may be worked out in successive strips.

Stripping.—In the Indiana district red clay covers the limestone beds to a depth of 1 to 20 feet or more. In some places it is stripped by power shovels into worked-out pits. The hydraulic method is employed where the surface contour favors washing the soil into abandoned pits or other low-lying areas. Mud seams are usually present in the upper level, and the hydraulic method is especially advantageous for washing clay from such irregular surfaces. However, loose rock fragments mixed with the clay may hamper removal by water, and some other process may be better. Hydraulic stripping has been described in a previous chapter (see pages 14 and 15).

A second phase of stripping involves the removal of overlying noncommercial rock, which at many quarries occurs to a depth of 5 to 15 feet immediately beneath the clay covering. In some quarries near Bedford 40 to 60 feet of such waste must be removed. The method of removal is governed chiefly by the nature of its contact with the underlying beds. If it is separated from the good rock by a layer of clay, shale, or an open bedding seam that serves as a cushion, it may be drilled and blasted with light charges of black blasting powder without danger of shattering the commercial rock. In some places, however, the rock overburden is continuous with that of good quality, which under such circumstances would be easily destroyed by the shock of an explosive. In such cases it is necessary to channel the waste and remove it in blocks, a stripping process almost as expensive as removal of good stone. A more recent development is adaptation of a wire saw for making cuts beneath the inferior rock, permitting explosives to be used without damage to the underlying ledge.

Where mud seams extend through waste rock into marketable stone the clay which accumulates during removal of the upper benches must be

removed as a floor-cleaning operation, which is not properly regarded as stripping.

Channeling.—After all overburden is stripped from the rock surfaces the next step is to make primary channeling-machine cuts for block separation. A channeling machine operates with a chopping action similar to that of a reciprocating drill. It is mounted on a frame with four wheels and travels back and forth on a track. The cutting tool comprises three or five steel bars sharpened to a blunt chisel edge and solidly clamped

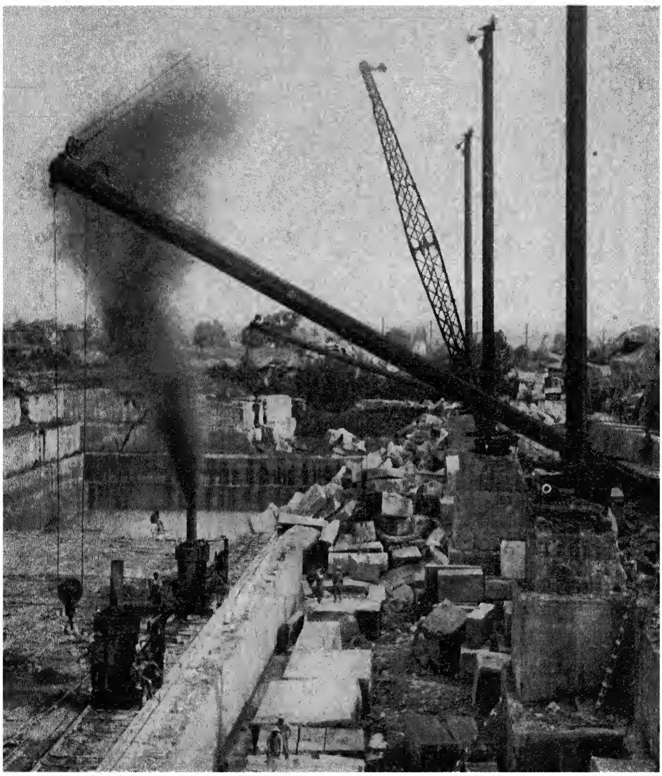

FIG. 4.—Steam channeling machines at work in an Indiana limestone quarry. (*Courtesy of Indiana Limestone Company.*)

together. When three bars are used the cutting edge is in the form of the letter *N*; when five are used they are in the form of two such letters, or with the second *N* reversed. On channelers of one type the cutting tools are secured with wedges to an upper and lower clamp. The bars are unclamped and lowered after every 6 inches of channel cut, and at a depth of 5 feet the 9-foot steel is changed for bars 14 feet long. On another type—the duplex electric channeler—the bars are set in a crosshead and changed every 2 feet. Steam channelers were once the only kind used and are still employed to some extent. They cut faster than

other types but require more labor. A steam boiler is attached to the machine which cuts a single channel. The blows of the channel head are actuated by a piston in a cylinder, the action being similar to that of a steam drill. Steel is changed about every 2 feet. Some are of the duplex type, but both machines work in the same channel. Single channeling machines are advantageous for cutting unusual widths. Steam channelers are shown in figure 4.

The duplex electric channeler is now widely used. The chopping action is accomplished with cranks driven by 25-h.p. motors and intensified by heavy springs. The machine operates on a track of 7-foot 2-inch gage and cuts a channel on each side. The cuts are 8 feet 4 inches to 8 feet $5\frac{1}{4}$ inches apart and may be 8 to 12 feet deep. The cutting edge of the steel is $1\frac{7}{8}$ to $2\frac{1}{8}$ inches wide and cuts a channel about 2 or $2\frac{1}{4}$ inches wide. The steel is reduced one-eighth inch for each change. Cuts may be 50 to 100 feet in length; for long cuts several machines operate on the same track. Some large quarries keep 20 or more machines in use.

When a pair of cuts is completed the tracks are moved and a second pair made. On the completed floor they average 4 feet apart, but occasionally are narrower or wider. In some regions channels are cut parallel with the east-and-west mud seams, while in other places they are at right angles to them. Cross channels are made only for wall cuts, for removal of key blocks, or as "head cuts" to divide strips that are too long to be turned down en masse.

Where mud seams are present the first cuts are made with some difficulty. Tracks must be supported with posts and scaffolding. It is difficult to keep a cut straight on an uneven surface, and channeling becomes slow and tedious until it has passed the irregularities. The addition of water is not feasible until a fairly continuous channel is obtained; therefore, cuttings must be removed by hand. In the regular process a stream of water carries away the cuttings as thin mud, and cutting is much faster wet than dry. After the quarry floor is leveled it is relatively simple to move and place tracks.

The rate of channeling is difficult to determine because some operators measure it in terms of actual cutting time, while others estimate on the basis of average accomplishment over a long period. The most reasonable time basis is "channeling hours," that is, the time for which machine operators are actually paid. Using such a basis for time, and regarding 1 square foot of channeling equivalent to $3\frac{1}{2}$ cubic feet of gross production, the calculated daily rate is 200 to 300 square feet for each duplex machine. Most operators will estimate a faster rate, but they fail to allow fully for all interruptions. The cost of channeling is 8 to 12 cents a square foot; in fact, it is the largest single item of quarry cost and may exceed half the total cost.

Wire Sawing.—The high cost of channeling has led some operators to attempt more economical methods. The unqualified success of the wire saw in Pennsylvania slate quarries offers encouragement, for there a wire saw will do the work of two or three channeling machines with much lower first cost, as well as lower operating expense. The wire makes a cut only about one-fourth inch wide and thus wastes little rock as cuttings. No tracks are required, the saw may be operated by one man, and the power charge is small. It is particularly advantageous in cutting upper

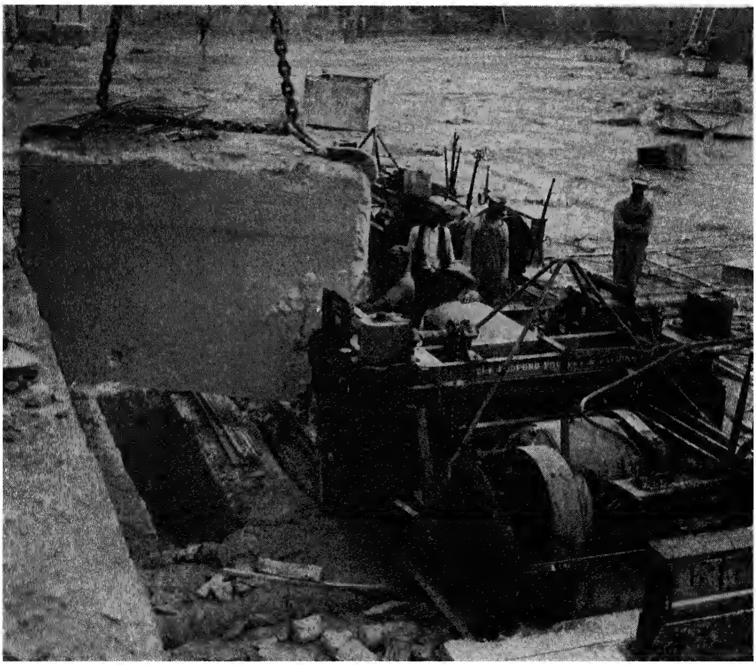

FIG. 5.—Method of cutting and removing key blocks in a limestone quarry. (*Courtesy of Indiana Limestone Company.*)

irregular beds. Its design and operation are described in detail in a subsequent chapter on slate (see pages 255–260).

Two Indiana companies were using this equipment with fair success in 1931. In one quarry a cutting rate of 26 square feet an hour was attained under rather unfavorable conditions. Another company made quite exhaustive tests in 1931. A cutting rate of 87 square feet an hour was attained, and the average cost during the second month of operation was 11.2 cents a square foot. Details have been published by Newsom,[8] who directed the work.

Removal of Key Block.—In opening up a new floor where no free face is present the most difficult task is removal of the first or key block.

[8] Newsom, J. B., Results of Wire-saw Tests. Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 117–121.

The block is channeled on four sides, and wedges are driven in the cuts to break it free at the floor. In some quarries, after an 8- by 8-foot block has been channeled the tracks are shifted, and two 2-foot blocks are channeled as shown in figure 5. The narrower masses, known as "pulling blocks," usually are comparatively easy to break loose by wedging in the channel cut. When the block is free, corners are chipped from the edges of the cuts to make room for the dogs or hooks, and the

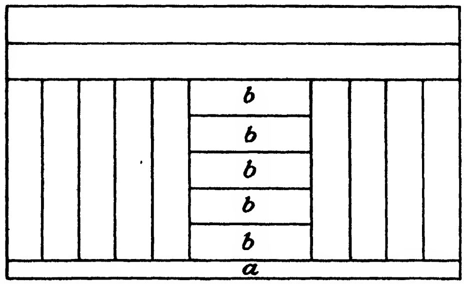

FIG. 6.—Arrangement of channel cuts for removing key blocks. *a*, 2-foot channel; *b*, key blocks.

block is hoisted out, as shown in the figure. If only part of the block is thus removed the process must be repeated with the lower sections. If unusual delay and difficulty are experienced in removing the first block, it may be advisable to break it up and remove it as waste. When it is out of the way floor space is provided for removing succeeding blocks. They are wedged free at the floor and removed one by one, providing a

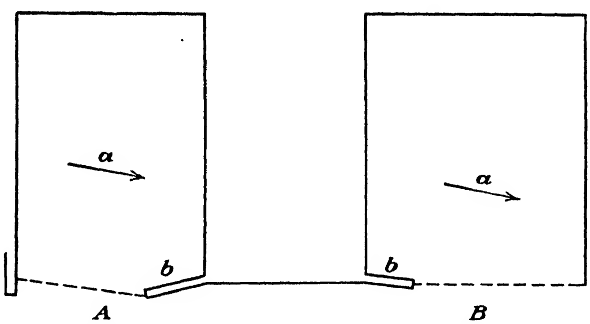

FIG. 7.—Diagram showing effect of rift on floor breaks. *a*, dip of rift; *b*, wedge holes. *A*, break in a direction up the dip of rift giving uneven floor; *B*, break in a direction down the dip of rift giving a more uniform floor.

wider working space. Another method of removing key blocks is shown in figure 6. The pulling blocks are in the center, as indicated. A mass 2 feet wide is removed along the wall to provide space for slush from the channelers. A third long cut is made 20 feet from the 2-foot space, and crosscuts 4 feet apart are subsequently channeled. When the pulling blocks are removed the 4- by 20-foot masses are turned down as

usual. Various modifications of the method are in use in different quarries.

Bed Lifting.—After masses of rock 4 feet wide, 8 or 10 feet deep, and 50 or 60 feet long are channeled, the next step is to separate them at the floor line by drilling and wedging. An air-driven hammer drill is used to sink a series of holes 8 to 12 inches deep, 1 foot to 18 inches apart, slanting a little downward from points near the floor line. They are not made at right angles to the wall but at such an angle that wedges placed in them may be sledged conveniently. They slant right or left, depending on whether the sledger is right- or left-handed. Plugs and feathers

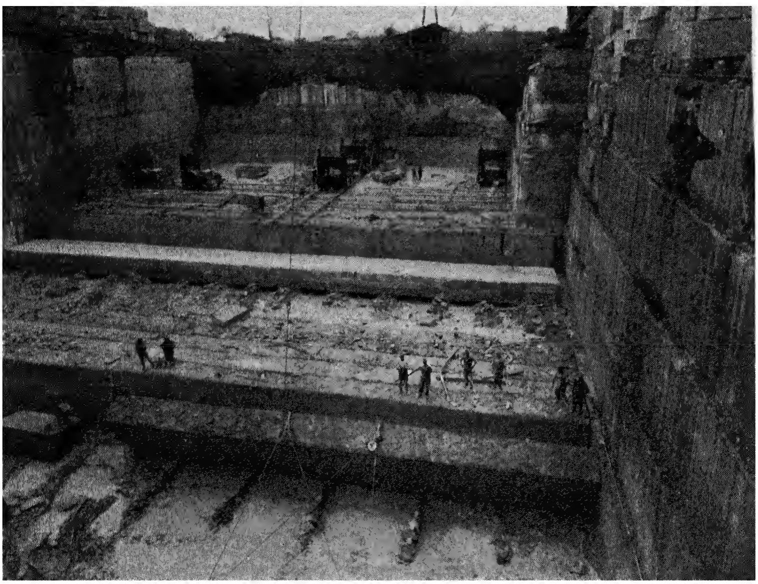

Fig. 8.—Method of turning down blocks in an Indiana limestone quarry. (*Courtesy of Building Stone Association of Indiana, Inc.*)

are placed in the holes and driven in succession until a floor break is made. At intervals wedges are driven to full depth, and the pressure being thus relieved most of them may be removed.

Commonly the rift of the rock is inclined at an angle of 5° to 10° from horizontal, which may result in a very uneven floor. It is best to quarry in such a way that floor breaks are made in the direction of dip of the rift, which then tends to hold or guide the break to the bottom of the channel cut, as shown in *B*, figure 7. If a break is made in the opposite direction it will follow upward on the rift from the bottoms of the shallow drill holes and reach a point several inches above the bottom of the channel cut, as shown in *A*, figure 7. The floor will then consist of a series of humps and hollows, and much waste rock will result.

More uniform breaks could probably be made by drilling some of the holes almost the full width of a block and using long wedges in them—a method in common use in marble quarrying—but apparently such a plan has not been tried in limestone.

Turning Down Blocks.—After a block is wedged free it is turned down in a horizontal position on the quarry floor before further subdivisions are made. On a long block two notches or dog holes are made in the back channel cut, wide enough to accommodate massive hooks. By means of sheaves and tackle these are connected with another pair of hooks firmly secured to the quarry floor some distance in front of the face.

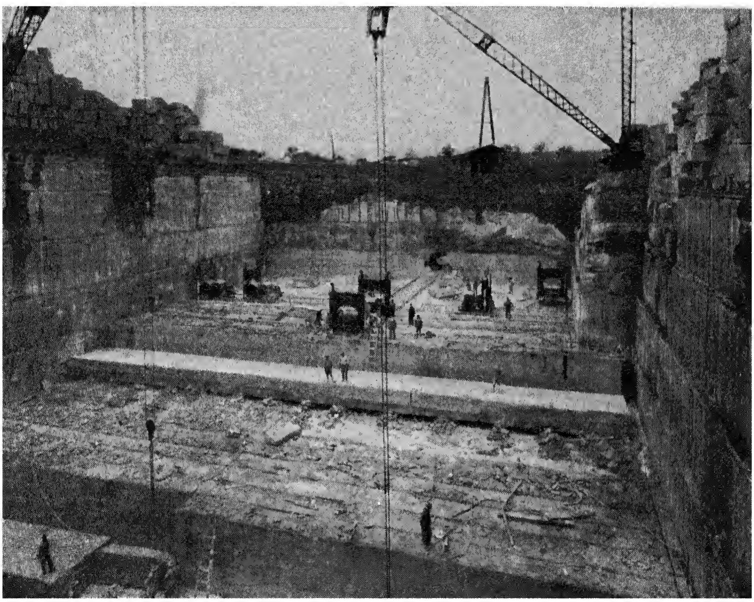

FIG. 9.—General view of a limestone quarry. (*Courtesy of Building Stone Association of Indiana, Inc.*)

When a heavy strain is exerted on the cable by the derrick hoist the block is gradually pulled over, as shown in figure 8. Bull wedges may be sledged in the back channel cut to assist the process. Piles of broken-rock "pillows" are so placed that the block falls on them and comes to rest with little impact and without danger of breaking. Such "pillows" are shown in figure 8. Figure 9 is a general view of a limestone quarry, showing an unusually large mass of stone just turned down.

Subdivision of Blocks.—The next step is to divide the mass of stone into commercial sizes. It is first laid out with a carpenter's square and straightedge; and if more than one grade of rock is present, a longitudinal break is made between the grades. All subdivisions are made by plugs and feathers or "slips and wedges," as they are called in Indiana. Holes

are drilled in line, 6 to 8 inches deep and 12 to 18 inches apart. Indiana limestone may be drilled rapidly. One man with a hammer drill can sink about four holes a minute. Plugs and feathers are then placed therein. "Feathers" are strips of iron flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole; two are inserted in a drill hole, and a "plug" (a steel wedge about 6 inches long) is driven between them. They are sledged lightly in succession, beginning at one end of the line, to maintain an even strain on the rock. Sledging is continued until a fracture appears. Common block sizes

Fig. 10.—Method of subdividing and hoisting limestone blocks. (*Courtesy of Indiana Limestone Company.*)

are 10 by 4 by 3 feet and 10 by 4 by 4 feet. Where mud seams occur or where separations must be made according to grades, many irregular sizes may be produced. Figure 10 shows the method of subdividing blocks.

Hoisting.—Steel or wooden derricks of about 30- to 50-ton capacity are used for hoisting blocks from quarries. The derrick masts, of swinging-boom type, are supported by 12 to 15 guy cables secured to dead eyes in the rock or attached to buried timbers. Derricks now in use have masts 80 to 110 feet high and booms 70 to 100 feet long. "Dog holes" are cut on opposite sides of a block to hold the tips of grab hooks (dogs). A chain passed through the eyes of the hooks draws them firmly against the block, holding it securely, as shown in figures 5 and 10.

The end block is first raised about 3 feet at the outer end and lowered again to the floor. This procedure crowds it outward, making a space of a foot or more for attaching dogs. Dog holes are cut, hooks attached, and blocks removed in succession and placed on cars or piled for later disposal. Workers become very skillful in choosing positions for attaching dogs so that blocks are balanced exactly. Each block is marked with letters or numbers in black paint to indicate its classification and for use in office records.

Cleaning Floor.—Waste-rock fragments, muddy cuttings from channeling machines, and clay from seams extending downward from the surface accumulate on the quarry floor and must be removed before a succeeding floor is channeled. The cleaning of floors is usually slow, costly, and somewhat disagreeable, especially in rainy weather. Waste is shoveled by hand into great iron dump pans, which are hoisted out and dumped into abandoned pits with the quarry derrick. If much waste accumulates a power shovel may be used.

Transportation and Storage.—As the average quarry block weighs 10 to 12 tons standard railway cars are invariably used for haulage. Large storage capacity is essential, for enough stone must be accumulated to supply the demands of the four winter months when quarries are idle. Outdoor storage or "stacking yards" may be maintained at quarries, at mills, or at both places. A common method of storage is to pile blocks within reach of derrick booms. They are usually piled high in a limited area, and at times it is difficult to sort them. Overhead traveling-crane storage is preferred by some operators, because the blocks are more accessible and handled more quickly.

Scabbling.—Some companies quarry only, and sell rough blocks to stone mills; others have both quarries and mills. Companies that own no mills frequently ship blocks to distant points, and these must be trimmed carefully to avoid freight charges on waste. The process of trimming blocks to uniform rectangular shape is known as "scabbling." It may be done at the quarry or storage pile and is, therefore, a sort of transitional process that may be classed with either quarrying or milling.

Several methods of scabbling are employed. Scabbling picks similar to ordinary miners' picks are commonly used to remove all irregularities. One point is bent at a sharp angle toward the handle for use in chopping dog holes for attaching grab hooks. Hand picks and spalling hammers also are employed to remove corner masses from blocks to be turned into columns. For squaring up ends of blocks some companies use two heavy disks of iron about 3 feet in diameter which run in opposite directions but in the same plane and with their peripheral edges nearly meeting. On the face of each disk are attached two single and one pair of cutting tools. As a block travels on a car the rotating disks cut down the surface. Blocks scabbled with this machine are

easily recognizable by the two sets of semicircular grooves or markings on their surfaces.

Scabbling saws are preferred by many, not only because they leave a smooth, even surface, but also because in a single operation they remove large projections which must be removed piecemeal by the pick or disk method. Scabbling saws are of various types. Diamond-toothed drag saws are used singly or in parallel pairs adjustable for width. Diamond-toothed circular saws (commonly of 60- or 72-inch diameter) cut rapidly, and if mounted in pairs adjustable in spacing may scabble both sides of a block at once. The greatest limitation of the circular saw is the depth of cut, as it can reach only from the arbor to the rim; a 60-inch saw can cut only 26 or 27 inches deep and a 72-inch saw, 32 or 33 inches. This difficulty is overcome by making one pair of cuts to the maximum depth the saws will reach and then turning the block over and cutting from the reverse side. If the cuts fail to meet the intervening rock is easily broken.

A clever adaptation of a Carborundum scabbling saw has been observed. The saw is mounted at the end of a shaft and secured with counter-sunk set screws flush with the outer surface. When a cut is made as deep as the arbor will permit the scabbled slab is broken off with a hammer; and a second cut of equal depth may be made, for the smooth outer surface of the blade interferes in no way with the sawed surface of the block.

Scabbling planers are effective substitutes for saws. Rough blocks are placed on a bed which travels between two sets of massive blades set at right angles to the block and with edges vertical. Irregularities are thus scraped from the surfaces of the stone. By screw-feed adjustment the cutters are set closer after each motion, until a smooth surface is obtained. On blocks 6 feet high each cut removes $\frac{1}{4}$ inch of stone and on blocks 4 feet high, $\frac{1}{2}$ inch. About three blocks may be scabbled an hour. A wire saw consisting of a $\frac{3}{16}$- or $\frac{1}{4}$-inch three-strand cable running as an endless belt driven by an electric motor is also used for scabbling. Where the wire comes in contact with the stone it is fed with sand and water. Several blocks may be lined up and cut at the same time. The equipment may be operated by one man, and an average cutting rate is 20 to 25 square feet an hour.

Various sawing methods are employed for slabbing off the sides of blocks; but the ends are usually scabbled with picks, although they are sometimes cut with wire saws or circular disk scabblers. The statement has been made that rough, scabbled blocks weigh about 200 pounds a cubic foot sale measurement, whereas smooth blocks weigh only 180 pounds a cubic foot, which indicates the advantage of scabbling by saw or planer. Scabbling is done most carefully where blocks are prepared for export trade or for shipment to mills long distances from the quarries.

MILLING METHODS

Mill Processes.—Quarried blocks are taken to mills for fabrication into finished products ready for use in various types of construction. Briefly, the steps in mill operation are drafting and pattern making, block transportation, sawing, planing (including curved and molded work), jointing, milling, turning, fluting, cutting, carving, packing, and shipping. These processes are considered in some detail in the following paragraphs.

Drafting and Pattern Making.—Before any cut-stone job can be begun accurate detailed drawings must be made of every piece of stone that differs from another in size or shape. Architects' drawings are usually insufficient, for the stone must be fitted accurately to the steel framework, and detailed data of the size and position of each steel member are necessary before stoneworkers' shop drawings can be made. These consist of elevations showing the position and dimensions of each piece of stone. Some sizes and shapes may be duplicated many times in a building; others may not be duplicated at all. Patterns for molded and carved work are of zinc or other soft metal; sometimes paper patterns or stencils are used. For the most intricate carved work plaster models are supplied by the stone mill or by the architect.

Few people realize how much labor and expense are involved in the drafting required for a large stone structure. This so-called "paper work" may cost one-half to two-thirds as much as the entire quarry expense of supplying the rough blocks of stone.

Ticket System.—After shop drawings are made draftsmen prepare a card or ticket for every block of stone. On each ticket is a drawing of the block with exact dimensions indicated. A number is assigned, and if a pattern is to be used the pattern number is given. Even though many blocks of one kind are to be made a ticket is prepared for each. The man in charge of gang-sawing first gets the ticket and cuts the block required. As this piece of stone passes to the planer, jointer, and all subsequent machines and operations, the ticket goes with it, and each workman consults it before any work is begun. By this means workmanship is constantly verified, and very few mistakes occur. The highest degree of care and skill is required, for one small error in measurement or one wrong blow with a tool may ruin a block on which much labor has been expended. The above system is used particularly in Indiana. In some New York mills one ticket or schedule is used for all blocks of a general shape.

Handling Blocks.—Overhead traveling cranes with at least 70-foot spans and lifting capacities up to 50 tons are used almost universally. Mills are of two general types. Some are wide and equipped with two pairs of crane tracks, one for a heavy crane used in handling quarry

blocks and placing them on the saw beds, while the second pair is furnished with lighter, more rapidly moving cranes for conveying smaller blocks as they pass from one operation to another. Some means of transferring stone from heavy to light cranes is required. Other mills are long and narrow, with one pair of tracks on which several cranes operate. For example, there may be a 25-ton-, a 15-ton-, and a 7½-ton-capacity crane on the same tracks. Some are of the three-motor type, one of which is used for propelling the entire crane from one end of the mill to the other, one for lateral motion to cover any point from side to side, and one for hoisting. Most of them are of the two-motor type, one motor with two friction clutches serving for both lateral motion and hoist. In a very short time a block may be picked up at any point in a mill and placed at any other.

Railway tracks enter the mills across the end, down one side, or across the middle. They bring quarry blocks to the mills and carry away finished products. All rough blocks and single unfinished slabs are handled with grab hooks; finished and semifinished blocks or piles of slabs, with cable slings or with slings of rubber belting to avoid damage to corners and edges. Operators travel back and forth in cabs attached to the crane. Some cabs are attached to one end of the crane, the operator always being near one wall; others are attached to the buggy that moves back and forth from one side of the mill to the other. The latter type has the advantage of placing the crane man always immediately above the blocks handled, so that he can guide the movement accurately and quickly. A ground force usually consists of two men, known as "hookers," who attach and release hoisted blocks and signal the crane man. This work requires much rapid walking back and forth in the mill, for cranes travel at high speed, and after hooks or slings are attached, hookers must as quickly as possible reach the point where the block is to be placed.

Sawing.—The first step in manufacture is to saw rough blocks, into either slabs or blocks, of the required dimensions. Gang saws are almost universally used for this purpose. They consist of a series of soft steel blades set in parallel position in a frame which has a backward and forward motion. These blades may be spaced as desired for thin slabs or thick blocks. Gangs vary in dimensions, one of average size being 14 feet long, 8 feet high, and 8 feet wide.

Abrasives are fed to the blades with water; those most commonly used are clean silica sand, most of which is obtained from Ottawa, Ill., and "chats," a name given to a cherty rock obtained as gangue at the Missouri lead and zinc mines and crushed to the consistency of sand. Steel shot is also employed, chiefly to obtain the deeply scored, "ripple-mark" surface desired for some architectural effects. When this type of abrasive is used the blades are notched on the lower edge and used in a

straight-line drag-saw frame. Most gangs are of the swinging type and are suspended from above by nearly vertical rods attached to the two ends. As the frame moves back and forth, actuated by a crank and connecting rod (pitman), the cutting blades lift toward the end of each stroke. This permits sand to wash under them, and as they start back on the return stroke the blade bears down on the sand which abrades the stone rapidly. Some gangs have a straight backward-and-forward motion, but the swinging type is more common. Sand or chats is collected in a concrete trough beneath the gangs and pumped to a box above the saws from which it is distributed, with fresh abrasives, to the cutting blades. If much shot is employed it is shoveled for reuse rather than pumped. An adjustable automatic gear feeds the gangs downward at any desired rate. In the Indiana limestone district an average rate is about 6 inches an hour.

A straight steel blade with diamond teeth on the lower edge is used as a drag saw for making single cuts. A drag tooth is mounted with six diamonds of about three-fourths carat size placed in alternate positions on opposite sides of the cutting face. A single tooth may cost $40 or $50. This saw will cut at a rate of 30 to 40 square feet an hour.

Circular diamond saws are used almost universally for making subsequent cuts. Common sizes are 60 and 72 inches in diameter, though smaller ones are sometimes employed. The blades are of steel one-fourth inch thick, with a series of square notches around the rim. Steel teeth mounted with diamonds are set in the notches and held in place with copper rivets. A 60-inch saw, a size widely used, has 84 teeth and a 72-inch saw, 110 teeth. Teeth for rip saws designed for heavy service are supplied with two ½- to ⅝-carat diamonds. Jointing-saw teeth contain 6 to 10 smaller diamonds, which give reasonably smooth stone surfaces and cause less breakage of corners than ripsaws. Circular-saw teeth cost $8 to $11 each. Extreme care and most exacting workmanship are required in the manufacture of diamond circular saws to insure accurate balance, uniform cutting, and true running. Each saw is designed for a standard speed (11,000 to 13,000 surface feet a minute) and should be run at no other. With care, a saw will perform constant service for 6 months to a year without being conditioned. Resetting costs about $1 a tooth if no diamonds are lost.

A ripsaw has a stationary mounting, and a bed actuated with a worm gear carries the block of stone beneath it. An exception is the gantry saw, which is mounted on a wheeled frame that travels on a track after the manner of a gantry crane and spans the block resting on a timber bed. A jointing saw is mounted on a movable frame actuated by worm gear, which carries the saw through the stone.

The cutting edge of a diamond saw is cooled with a stream of water, which also carries away the cuttings. An average sawing rate is 3 to 16

inches a minute, depending on the depth of the cut. Ripsaws cut faster than jointers. The first cost of a diamond saw is high, but it cuts rapidly, and with care maintenance cost is low.

Silicon carbide (Carborundum) circular saws are also in common use. They are usually smaller than diamond saws and are of two types—continuous rim, which are more generally employed, and toothed, which are larger, approximately 30 inches or more across. They give excellent service for the smaller cuts, as they leave smooth surfaces and are less liable than diamond saws to chip the corners of stone blocks.

Some experiments are being performed in mounting saw teeth with extremely hard alloys, such as tungsten carbide. Commercial development has scarcely been attained, but the field offers wide possibilities.

Planing.—Planers are used for cutting stone blocks and slabs to smooth surfaces and desired thickness and also for cutting moldings. The frame that holds the cutting tool has lateral and vertical motion, actuated by power-driven worm gear. The cutter is placed in position, and a block of stone is carried beneath it on a traveling bed called a "platen" at a rate of 30 to 45 feet a minute. A thin layer of stone is thus scraped from the surface, and the process is repeated until proper shapes or dimensions are obtained. Machines are equipped to cut tops and sides of blocks simultaneously. For cutting moldings tools are shaped in the blacksmith shop to fit exactly against patterns; that is, the tool is the reverse of a pattern. If a great length of molding of one profile is to be made, a Carborundum wheel, shaped in reverse form or as a negative of the pattern, may be used, but in limestone the planer is employed more commonly for this work. For both flat and molded work the planer is a time saver, its estimated production being equivalent to that of seven stone cutters using hammer, chisel, and modern pneumatic tools.

Planers are adaptable for curved as well as straight work. A second bed or platen, capable of rotating through an arc of a circle, rests on the regular bed. On some planers an arm pivoted on a fixed point at one side is connected with the upper bed, and its length governs the curvature of the arc. Another type is guided by a pin following any one of a series of curved grooves having different radii. If a radius approaching 12 or 14 feet is required, it is accomplished through movement of the outer end of the bar in a slot set at an angle. A stone block is placed on the upper bed, and when the planer is operated in the usual way the tool cuts a curved form, the shape of which is governed by the motion of the block and the pattern of the tool. Garden seats and arches for doors, windows, or ceilings are made with such machines.

A Carborundum planer consists of two saws with a drum of smaller diameter between them, all of silicon carbide. The saws trim the sides of slabs while the drum smooths the upper surfaces. The planer bed

travels at a rate of only 20 to 30 inches a minute, but it finishes the job in one cut and accomplishes much more in a given time than an ordinary planer with which many successive cuts may be required.

Turning and Fluting.—Lathes are employed for turning columns, balusters, and similar forms. Large columns are first scabbled to cylindrical shape and then mounted in lathes, essentially the same as those used for wood or metal turning. The column rotates against a tool actuated by machine-driven worm gear traveling slowly back and forth the full length of the stone. The tool post is moved forward or backward by a hand or automatic screw feed, which may be adjusted for any change in diameter required for tapered columns. Limestone columns are turned to a smooth surface, but final rubbing is usually by hand. Ordinary lathes will handle 15- to 30-foot columns, and some are specially designed for massive 50- or 60-foot columns. Smaller sizes are used for balusters.

Many columns are fluted, the fluting is done on a lathe. A column is first turned to the desired outer dimensions. The width and length of the flutes are then laid out on the surface with pencil. The column remains stationary while the fluting tool attached to the tool post of the lathe travels back and forth. This process is continued until the line bounding the flutes is reached. If a column is tapered the flutes may be cut to shallower depth on the smaller parts of the column, which automatically makes them narrower. When a flute is completed the column is rotated with a hand bar, and the process repeated in the new position. After this machine work the ends of the flutes are finished with pneumatic tools, and the column is rubbed by hand. Carborundum fluters are also used. A Carborundum wheel cut as a negative of the pattern is generally used for making balusters, particularly if many of one kind are to be fabricated.

Milling.—Some confusion exists in application of the term "milling." The word is used in a general way to cover all mill processes, such as sawing, planing, cutting, or carving, and is also applied to a particular type of equipment known as a milling machine. This machine consists essentially of a rotating head with right-and-left and vertical worm-gear motions. A movable platen provides front-and-back motion. The head carries tools of various sizes and shapes, by means of which stone may be cut in irregular patterns. This machine is particularly advantageous in preparing for the carvers blocks in which deep recesses must be cut, for it removes the bulk of the stone much more rapidly than it can be cut away with hand tools. A skilled milling-machine operator can outline lettering and intricate patterns, thus reducing hand carvers' work substantially.

Cutting and Carving.—Cutting is usually defined as straight-line work and carving as curved work. Carving requires more skill than

any other limestone-cutting operation and is usually done by experienced workers. Many years ago all carving was done with chisel and mallet, and these tools are still necessities for certain operations. Modern pneumatic tools, however, have revolutionized the art and greatly increased the production per man. The great bulk of the work is now done with them.

At first the use of compressed-air tools was vigorously opposed. It was feared that the art of stone cutting would be destroyed, and that health would be impaired through vibration of the tools. Such fears were unfounded, for pneumatic tools enhance the skill and artistry of the carvers and lighten labor to a marked degree. Many a stonecutter of advanced age, who could not bear the strain of constant toil with chisel and mallet, has found his labor so lightened by pneumatic tools as to add several years of active work to an already long experience.

The stonecutter uses a great variety of tools, heavy ones for removing larger fragments when blocking out a design and smaller ones for completing the work. Intricate carving may require tools almost as fine as those of a dentist. Patterns insure accuracy and symmetry. A pattern may be placed on the surface of the stone and marked around the border or through perforations, or the design may be transferred by dusting with burnt umber. Models of the most complicated figures are made in plaster of paris, and reproducing them in stone is work of the highest skill.

Carving adds greatly to the expense of preparing stone. Architects who design structures requiring much hand carving must expect a cost per cubic foot much higher than that for buildings consisting of plain blocks. Oolitic limestone, however, carves more easily and tends to split on the bed less than most other limestones, bringing it within a cost range which greatly widens the field of carved-stone architecture. Many beautiful structures, churches, chapels, libraries, and other public buildings bear witness to the adaptability of oolitic limestone for carving.

Finishing.—Much limestone used in buildings has no other surface finish than that given by machines with which it has been worked. Certain parts, however, such as columns, may require smoothly rubbed surfaces. Usually final finish is done by hand, the stone being rubbed down wet or dry with sandstone, sand and water, or bricks of artificial abrasives. A small electric-driven disk faced with sandpaper may finish flat surfaces. Steel scrapers are also used and wire brushes employed to brush all cuttings from the surface.

Nature of Finished Surfaces.—Architects and builders demand various types of surface finish. A *tooled* surface, which is covered with fine grooves in parallel lines, is made with a pneumatic or planer tool having fine teeth. A *bush-hammered* surface is rough and pitted, as the hammer used has a face covered with small projections. A *hand-picked*

surface is indented with a sharp-pointed tool. A *small-fluted* surface has small, parallel corrugations. A *four-cut* surface is made with a planer tool that has four corrugations to the inch. A *rubbed* surface is smoothed by hand rubbing with sand and water or some other abrasive. A *shot-sawed* or *ripple* surface is deeply scored or grooved by using steel shot as abrasive for the gang saws. *Chat-sawed* stone is rough but smoother than the shot-sawed. The chats used as abrasive in sawing are of three different grades of fineness to give smoother or rougher surfaces as desired.

Preparation for Shipping.—Building stone is a product so heavy that provision must be made for handling all blocks by machinery, in such a way that corners or edges will not be broken. For smaller pieces a pair

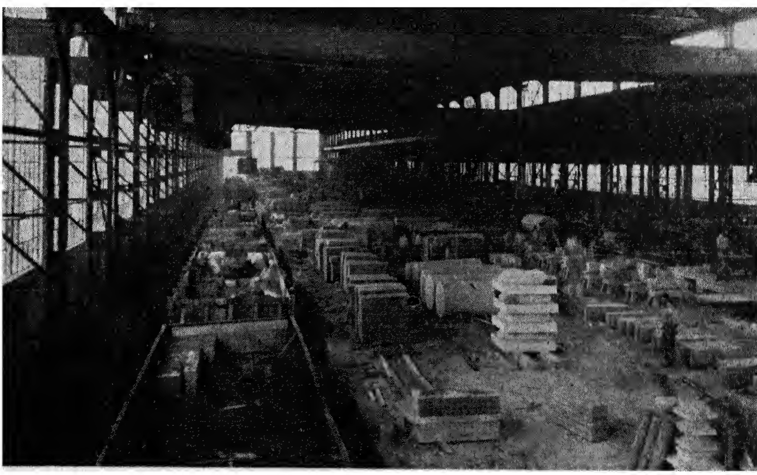

FIG. 11.—Interior of a limestone finishing mill. (*Courtesy of Indiana Limestone Company.*)

of converging holes is drilled in an edge or face that will be covered when the block is in final position in a building. Lewis pins, with eyes at the top, fit loosely in the holes. Through them a chain is passed, and as it is drawn tight the pins bind so firmly that the block can be hoisted safely. For large, heavy blocks Lewis key pins are commonly used. The holes which are drilled for them are enlarged at the bottom. The two side keys are wide at the base and held apart in the hole with a center key inserted last. All three are secured with a bolt which passes through holes in their upper ends and also holds a ring for hoisting. Much handling is done with slings or chains, lumber being used to protect the edges. All blocks are numbered and lettered, to show their positions in the structure in which they are to be placed, and carefully packed for shipment, usually in open-top gondola cars. Each block is surrounded with excelsior and limestone dust and packed so solidly that no damage

can result during shipment. For the Department of Commerce Building in Washington, D. C., one of the largest stone buildings in America, nearly 70,000 blocks of Indiana limestone averaging 1,500 pounds in weight were used; 1,100 railway cars were required to haul the finished stone.

Figure 11 illustrates the interior of a modern limestone finishing mill.

LIMESTONE PRODUCTS

Some companies quarry and saw only, selling the stone in blocks or slabs. Standard-size blocks are most salable and command the highest price. Because of the presence of mud seams or other reasons odd-size blocks, usually designated "chunks," are necessarily produced. The quarry operator who has no mill suffers some disadvantage, for while off-size blocks may with judicious management be utilized to advantage they are not disposed of readily and command a low price.

A second and larger group of companies both quarries and manufactures stone into finished products. The mills are either at quarries or in near-by towns, the latter usually being preferred because the labor requirement is large, and living conditions are more favorable than in most quarry regions. A third group of companies buys sawed or rough stock and manufactures products, but does not operate quarries.

Therefore, rough blocks, slabs, and cut stone or other forms of building stone are the products chiefly marketed. Cut stone includes all types of finished blocks, columns, sills, moldings, balusters, and carved stone. It is the chief, though not the only, product of many limestone mills.

A rougher type of building stone, known as "sawed or broken ashlar," is not usually regarded as a cut-stone product. It is particularly adapted for residential work, though it is also used in larger structures. It is much less expensive than cut stone and thus brings homes, having the permanence and dignity of stone, within the cost range of people of moderate means. This type of ashlar is fabricated in sawed strips usually 3 or 4 inches thick and in different height units that will combine to give even-range levels if desired. It is sold either in strips, cut on the job to specified or standard lengths that will fit together and make even corners with very little cutting, or sawed on four sides and broken to give various lengths. Random sizes and mixed colors give very attractive effects. Rough ashlar is comparatively inexpensive, because it requires no drafting or pattern-making, no machine work except sawing, no cutting or carving, and no careful packing for shipment and because it may be set by a stone mason or brick layer. Its use is advantageous to the producer because it permits him to use many small sizes that would otherwise be wasted. It is of benefit to the user because it makes

it possible to build innumerable homes of moderate cost, low upkeep expense, high rental and sales value, and attractive, dignified appearance.

COST OF QUARRYING AND MANUFACTURE

Quarrying and milling costs are both variable because they depend on conditions that may be quite diverse in different localities, for example, depth of overburden, degree of hardness of the rock, type of equipment used, working efficiency, skill of the workers, and size of operation. The general range of quarry costs is 20 to 30 cents a cubic foot of block stone. The chief item is channeling, which ranges in cost from 8 to 12 cents a cubic foot of recovered stone.

Milling costs are extremely variable because some blocks have little work expended on them, and others require much labor. Sawing is a heavy item of expense, the subdivision of rough blocks into slabs by gang saws costing 35 to 45 cents a cubic foot of finished product. Sawing in a second direction (jointing) costs 12 to 15 cents more. Planing, milling, and cutting costs must be added for most products. Carving is very expensive because so much labor is required per cubic foot produced. Gothic carving is one of the most difficult operations to estimate; it may cost as much as $7.50 a square foot of surface carved. The handling of material is an item that should not be disregarded. Paper work, including drafting, shop drawings, tickets, and patterns, may cost 15 to 20 cents a cubic foot on average jobs and exceed $1 a cubic foot on elaborate structures. For jobs requiring a moderate amount of carved work the total cost is $1.50 to $2.50 a cubic foot. If much carving, column cutting, or curved work is demanded it may be much higher.

WASTE IN QUARRYING AND MANUFACTURE

Rock of inferior quality, which is regarded as overburden rather than waste, usually overlies the Salem beds and is removed before quarrying is begun. Aside from this overlying material, waste in the commercial oolitic beds is high, and efforts are being made to discover ways in which it may be reduced. Some of the waste is due to rock imperfections and some to rock lost in quarry processes. The problem of waste has been discussed in some detail by Newsom.[9]

Coarse texture was once regarded as a serious imperfection, but tests have shown that coarse-grained stone compares favorably in durability and strength with that of finer texture, and modern demands for variety rather than absolute uniformity in texture have led to its wider use. Fine-grained rock always has been in demand and still commands a premium.

Erosion cavities filled with clay cause much waste, particularly in the upper beds. Many small, irregular blocks, necessarily produced,

[9] Newsom, J. B., Quarry Waste in the Indiana Limestone District. Am. Inst. Min. and Met. Eng. Tech. Pub. 444, 1932. 10 pp.

are discarded because they can not be used advantageously. Incipient seams or "drys," small cracks difficult to detect, must be carefully avoided. Some quarries contain many of them, and others have very few. They are excluded so carefully that they are rarely seen in blocks used for building. Stone is sometimes rejected because it is variegated in color, but present demands have led to a wider use of such material.

Further waste results from quarrying processes. It is estimated that 1 square foot of channeling is required for each 3½ cubic feet of gross production. Therefore, if each channel cut is 2¼ inches wide at the top, 4 to 5 per cent of the rock is cut away. Uneven floor breaks may cause the loss of a zone of rock 1 foot or more deep at the bottom of each floor. Crooked cross fractures, strain breaks, cutting of dog holes, and other factors incident to quarrying further increase the waste. It is estimated that not more than 40 per cent of the rock stripped and blocked out in a quarry is recovered in usable form. Much high-grade commercial material is also wasted as it passes through the mill in the manufacturing process. Outside slabs from gang saws and rough ends from jointers reduce the volume of every block by several per cent. Saw blades convert much rock into fine mud. Each diamond-saw cut and each stroke of a planer takes its small toll of stone, while in making curved and irregular designs more than half of the mass may be cut away. It is estimated that mill waste amounts to between 10 and 20 per cent of the gross footage entering a mill. The smaller percentage is in mills where material is utilized to best advantage as, for example, where cubical blocks are sawed diagonally to make two triangular corner blocks or two cornices wide at one end and narrow at the other.

UTILIZATION OF WASTE

Limestone of commercial grade in the State of Indiana generally analyzes 97 to more than 99 per cent of total carbonates. Building limestones in various other States are also of high purity. Pure limestones are useful for many chemical purposes, and some operators have sought to develop markets that will absorb part of their waste materials. Some high-grade material is burned into lime, which is used widely, not only for mortar and plaster, but in paper mills and steel furnaces and for water purification. Finer sizes of waste are used as agricultural limestone, in glass factories, for tennis-court surfacing, as chicken grit, or as filler. Many thousand tons from 4- to 12-inch size are sold as flux for open-hearth steel furnaces, for which a very low silica content is demanded. Many carloads of stone ranging from 1- and 2-man sizes to stones weighing 30 tons are sold as riprap and breakwater stone. Slabs of attractive colors are sold as stepping stones, flagging, and for garden walks. If the stone is suitable it may be utilized as railway ballast and concrete aggregate. Mill ends and other small sizes are converted into ashlar. While

waste limestone can be used for many purposes, the amount consumed is a mere fraction of the thousands of car loads of quarry and mill waste now discarded.

LIMESTONE MARKETING

Under normal marketing conditions two-thirds to three-fourths of all building limestone is sold as rough blocks or sawed slabs to mills situated in large cities, where it is fabricated chiefly for small or moderate-size building contracts. The balance of the production is manufactured in mills operated in the quarry districts. Much of their output is devoted to large projects. These mills, supplied only with shop drawings, can fabricate stonework for a structure hundreds of miles away and can supply in exact dimensions and in finished form thousands of blocks, each fitted accurately for its particular position in the wall. Although furnishing stone for large buildings directly from quarrying centers is perhaps the most spectacular phase of limestone marketing, the importance of mills situated in consuming centers must not be overlooked. They perform a vital function, for they supply stone to innumerable users, many of whom require quantities too small to be obtained directly from the great quarrying and milling centers.

The smaller limestone quarries in various States sell much of their production directly to builders and contractors for local use. Some, however, undertake fairly large building contracts or supply limestone to be used in conjunction with other varieties of stone in both near and distant projects. Some of it is handled through local mills in many cities.

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CHAPTER VII

SANDSTONE

VARIETIES

The term "sandstone" is applied to rock composed of small mineral grains, usually quartz, which are cemented together more or less firmly. "Conglomerate" is a name given to rock consisting of pebbles of various sizes which are cemented together; if the pebbles are large and well-rounded the rock is sometimes called "puddingstone"; if angular in shape it is called "breccia." "Quartzite" is a variety in which the individual grains are cemented together with quartz so firmly that the rock fractures as easily through the grains as through the cement. Some quartzites look like massive quartz with scarcely a trace of their original fragmental character. A "ferruginous" sandstone is one rich in iron and a "micaceous" sandstone, one in which mica flakes are prominent. "Arkose" is a feldspathic or granitic sandstone composed of angular grains which have resulted from the disintegration of granites, the debris thus formed having been recemented into solid rock without any extensive water action or decomposition. The siliceous sandstones may originate from similar granite rocks, but they have been so thoroughly decomposed and worked over by water before cementation that practically nothing is left of the original rock except the rounded grains of quartz. A "calcareous" sandstone is one containing a considerable amount of calcium carbonate, and an "argillaceous" sandstone one containing an appreciable amount of clay.

Sandstones are also named from their characteristic colors, such as "bluestone," "redstone," or "brownstone." The term "bluestone," however, is applied to certain thin-bedded or easily cleavable sandstones irrespective of color. The name "flagstone" is applied to sandstones that split readily into thin slabs or sheets suitable for flagging. "Freestone" is a sandstone that can be cut or carved readily with equal ease in all directions. "Ganister" is a type of quartzite suitable for the manufacture of silica brick.

COMPOSITION

Sandstones consist essentially of quartz; some are nearly pure quartz. Those consisting principally of other materials are rarely found, although many contain minor quantities of feldspar, garnet, magnetite, and mica. Muscovite or white mica is a common constituent. Iron oxides, calcium or magnesium carbonates, and clay are other common accessory minerals.

SIZE AND SHAPE OF GRAINS

The grains of which sandstone is composed vary greatly in size. Some sandstones are so fine-grained that they may be used for razor hones. A screen test of a typical sandstone from the famous Amherst (Ohio) district indicates that practically all the grains will pass through a sieve having 40 meshes to the linear inch, and that one-third of the grains are finer than 100-mesh. Sometimes the coarser, angular-grained sandstones are called "sandstone grits"; however, the use of this term is often confusing because it is applied commercially to sandstones which are well-adapted for abrasive purposes and not necessarily to those of coarse grain; for example, the "Berea grit" of northern Ohio is in places very fine-grained. Grains of sandstone may be well-rounded or angular, depending upon the degree to which they were waterworn before consolidation.

As pointed out in the section on the origin of sandstone, water has the ability to sort and classify loose materials according to size. Some deposits show remarkable uniformity in size of grains, a very desirable feature. Usually the sizes of grains are nearly uniform throughout the rock of one bed, and much greater variation is found in passing from one bed to another. This is to be expected because sand of an individual bed has been deposited under nearly uniform conditions over a wide area, whereas succeeding beds may have been deposited after long intervals and under quite different conditions of depth or water movement.

CEMENTATION

The usefulness of a sandstone depends greatly upon the nature of the cementing material between the grains and the degree of cementation. Of the four common cementing materials—iron oxides, clay, calcite, and quartz—the last is most desirable, as it provides the strongest and most durable stones. All stages of cementation are found in nature, from incoherent sandstones that may be crumbled between the fingers to indurated quartzites. All types between these extremes are used commercially, but friable sandstones are useless as dimension stone. Some sandstones are cemented more firmly in certain parts than in others. Such lack of uniformity causes hard and soft spots, an undesirable condition for all ordinary uses.

As the cementing materials and degree of induration vary greatly sandstones are the most variable of all common rocks in hardness. Confusion may arise from this statement, for it may be supposed that as all siliceous sandstones consist essentially of quartz, which has a hardness of 7, all sandstones will have the same hardness. However, this quality, which is a measure of the ease with which stone may be scratched, is governed by the degree of cementation, for scratching loosens individual

grains. Hardness, therefore, refers to the degree of adhesion between grains rather than to the resistance offered to abrasion. In this sense, therefore, it is synonymous with workability.

COLOR

The purest sandstones are nearly white. Iron oxides are the more important coloring agents. Limonite ($2Fe_2O_3.3H_2O$) usually gives yellow, brown, or buff shades, and hematite (Fe_2O_3), darker brown or red. Oxidation of iron-bearing minerals upon exposure may cause the rock to change in color. If the change is uniform throughout, the general aspect of the rock may not be impaired, but changes in streaks and spots may detract greatly from the appearance.

Permanence of color is usually desirable. Generally the deeper shades of red, brown, yellow, or buff are permanent because they are due to the presence of the stable iron oxides—limonite or hematite. Blue or gray sandstones, which occur deep down in the lower ledges of a deposit, may contain ferrous sulphides or carbonates which upon exposure will oxidize to the more stable forms with gradual change to a buff or reddish color.

Although it is generally claimed that uniform color is desirable, for certain architectural effects diversity is now in demand. Blocks of stone that would at one time have been thrown on the waste heap on account of nonuniformity of color distribution are now being utilized for ornamental building.

POROSITY

Sandstones are generally more porous than other rocks, although quartzites may have as little pore space as granites. The percentage of porosity of commercial sandstones ranges from 2 to 15. High porosity, especially if the pores are small, is undesirable if the stone is exposed to the weather in cold climates.

Pores or intergranular spaces in sandstone may be divided into two classes—capillary and subcapillary. The former group includes openings more than 0.00002 centimeter in diameter, and the latter, those of smaller size. Water in pores of capillary size, termed "water of saturation," passes off readily when the rock is exposed to a dry atmosphere. Subcapillary pores contain "water of inhibition," which is released with greater difficulty.

Normally the intergranular spaces of sandstone in an undisturbed quarry ledge are completely filled with "quarry water," which, particularly that part defined as "water of inhibition," carries mineral matter in solution. When the water evaporates the dissolved material is deposited as a cement between the grains, making the rock appreciably harder, and subsequent wetting will not soften it. As evaporation takes place

at the surface, a sort of casehardening results. For this reason freshly quarried sandstone works more easily than seasoned blocks. However, some recent investigations indicate that the surface-hardening effect is less pronounced than has been supposed.

The time required for the escape of quarry water depends on pore size and rock structure. Rock with subcapillary pores requires a long drying period, and one that parts easily along bedding planes usually dries more quickly than one with no rift or direction of easy splitting. If sandstone is exposed to frost action while the pores are filled with water, the expansion caused by freezing may result in serious disintegration. Blocks should therefore be quarried in time to dry before a heavy frost. Quarrying is usually suspended in cold climates during the late fall and winter. Sometimes quarries are protected from damage in winter by flooding them with water, scattering quarry refuse over the floor, or covering the vertical face with cornstalks.

USES

Building Stone.—Sandstone is used principally for exterior and interior building; that having siliceous cement is especially useful for exterior work because of its insolubility. It may be sawed or cut as even-course stone or as broken ashlar and used for entire walls or for trim on buildings made chiefly of brick or other materials. It is also employed for steps, sills, water tables, coping, pillars, or columns. For interior use the more attractive types are demanded, particularly the fine-grained stones adaptable for carving. Sandstone with low absorptive properties is used in lavatories. That which splits readily into thin slabs is used for floor tile.

Strong sandstones available in large blocks are used in bridge and dam construction and in sea walls, retaining walls, and dock facings. Irregular fragments having one good face are used as rubble. Sandstone is commonly built into attractive masonry walls around cemeteries and country or suburban estates.

Paving and Curbing.—Sandstone is used quite extensively for street paving. Only those stones which consist of grains firmly attached to each other with siliceous cement and which thus approach quartzite in texture resist abrasion sufficiently to make good paving stones. Some authorities claim that moderately cemented rock is better than quartzite for paving because it presents a gritty surface and wears at about the same rate as the cementing material in the cracks, thus maintaining a level rather than a smooth, rounded surface. Sandstones that have a good rift (easy bed splitting) and a good run (a second direction of easy splitting, perpendicular to the bed) may be trimmed most readily and therefore are most suitable for paving stones.

Curbstones may be made of material softer than that used for paving stones. They are manufactured extensively in conjunction with paving stones and at quarries where building stone and grindstones are made. If the rock splits readily, curbing may be split out and hand-trimmed at the quarry. The more massive sandstones are sawed into curbing. Production is about five times as great in value as that of paving stones.

Flagging.—A type of sandstone known as "bluestone" is well-adapted for flagging or sidewalks because it splits readily into thin, uniform slabs of large size. Sandstone is also sawed into thin slabs for sidewalks, but concrete is used for this purpose so universally that production of flagging is now a very small part of the industry.

Grindstones, Pulpstones, and Other Abrasives.—Only sandstones having special properties may be used for grindstones. The grains should be uniform, moderately fine, angular rather than rounded, and cemented in such manner as to grind steel readily and at the same time wear rapidly enough to prevent glazing of the surface. At several quarries, especially in Ohio, grindstones are manufactured in various sizes up to 7 feet 6 inches in diameter. Many similar stones are manufactured to grind pulpwood for making paper. Small pieces of very fine-grained sandstone are used for making grindstones to sharpen cutlery and scissors or for making hones, whetstones, and scythestones.

Buhrstone is a type of sandstone particularly adapted for the manufacture of millstones. Foreign buhrstone is a hard, tough, porous rock consisting of silica mixed with calcareous material. American buhrstone is a quartz conglomerate occurring on the eastern slope of the Appalachian Mountains, notably in New York, Pennsylvania, and Virginia. The New York variety, known as "esopus" stone, occurs in a strip about 10 miles long extending southward from High Falls in Ulster County. The Pennsylvania variety, known as "cocalico" stone, occurs in Lancaster County. In Virginia similar rock, known as "Brush Mountain" stone is found near Blacksburg, Montgomery County. Millstones were used extensively for grinding equipment 50 years ago, but the industry has declined greatly, partly because of the gradual disappearance of the old master craftsmen skilled in dressing the stones and partly because of the development of more efficient methods of grinding grain, paint, and minerals.

The manufacture of sandstone into abrasive products is a declining industry. Synthetic abrasives of the aluminum oxide or the silicon carbide type made in electric furnaces are gradually displacing those of natural rock origin. Segmental Carborundum pulpstones have lately come into use.

Miscellaneous Uses.—Sawed slabs of fine-grained sandstone are used widely for grave vaults. Dense, impervious rock is cut into thin slabs for constructing laundry tubs and similar plumbing fixtures. Small

Dimension Sandstone Sold or Used by Producers in the United States, 1929–1930 and 1936–1937, by Uses

Use	1929		1930		1936		1937	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Building stone, cubic feet	4,870,670	$2,666,314	4,953,660	$3,395,837	1,013,020	$ 965,493	1,965,480	$ 944,952
Approximate equivalent in short tons	347,440	....	383,160	....	83,910	....	147,920	
Paving blocks, number	3,674,800	291,608	4,337,870	321,486	471,350	31,726	12,950	648
Approximate equivalent in short tons	40,890	....	49,500	....	4,740	....	130	
Curbing, cubic feet	2,092,210	1,668,541	1,693,043	1,360,643	338,420	318,107	337,790	314,058
Approximate equivalent in short tons	167,660	....	124,220	....	26,230	....	25,600	
Flagging, cubic feet	729,230	557,720	774,920	615,439	353,650	303,843	445,280	419,788
Approximate equivalent in short tons	55,770	....	58,770	....	29,190	....	35,280	
Rubble, short tons	43,840	102,524	28,420	61,586	18,380	36,502	22,700	41,297
Total (quantities approximate, short tons)	655,600	$5,286,707	644,070	$5,754,991	162,450	$1,655,671	231,630	$1,720,743

amounts are fabricated into electrical switchboards and billiard-table tops, and line furnaces and acid tanks. Cubical blocks may serve as footings or underpinnings for posts under heavy structures. Sandstone is employed for monuments to a very small extent. Highly indurated quartzite is used for grinding pebbles and for tube and ball-mill linings.

PRODUCTION

The accompanying table, compiled from figures supplied to the United States Bureau of Mines, shows production by principal uses of sandstone employed as blocks or slabs.

INDUSTRY BY STATES

Sandstones suitable for commercial use occur in widely distributed deposits in nearly every State. Those that have been worked for dimension stone on a fairly extensive scale during recent years are described by States in alphabetical order.

Arkansas.—Novaculite, a highly siliceous sedimentary rock suitable for abrasive purposes, is quarried at Hot Springs, Garland County. The value of the stone depends upon its peculiar texture. It consists of minute, interpenetrating, sharp-edged crystals with innumerable small cavities between them—an ideal condition for maximum cutting power. The rock is used chiefly for the manufacture of oilstones and whetstones.

California.—Sandstones of many varieties occur in more than 20 counties but during recent years production has been confined to only a few quarries. A massive blue-gray and buff sandstone that has been used for several notable buildings in San Francisco came from a deposit extending for 8 miles in the northern part of Colusa County, but there has been no recent production. A moderately fine-grained arkose sandstone used more for breakwaters than for buildings is found west of Chatsworth, Los Angeles County. A deposit of buff sandstone was worked many years at Graystone, Santa Clara County, and provided stone for buildings at Stanford University. Brown sandstone occurs abundantly in Lespe Canyon, Ventura County. Stone for rough construction is quarried in Santa Barbara County at times. A porous, argillaceous sandstone merging into shale is quarried near Carmel, Monterey County. An unusual feature is the presence in some of it of a high precentage of opaline silica. It is used for building patios and houses, as garden-wall rock, and for flagstones.

Colorado.—A sandstone that has been quite popular for building purposes at times is quarried near Turkey Creek, Pueblo County.

Connecticut.—Sandstones of Triassic age occurring in the Connecticut River Valley formerly were worked extensively at Portland, Middlesex County. The well-known "Portland brownstone" was widely used as building stone in New York, Brooklyn. and other eastern

cities. The deposit is large, extending from New Haven to northern Massachusetts, or about 110 miles, with an average width of 20 miles. At Portland the stone is uniform, medium-grained, and reddish brown and lies in solid, nearly horizontal beds. Though quite porous, most Triassic stone is durable if carefully selected and properly used. Complaint has often been made of the spalling of brownstone in buildings, but deterioration has been due more to faulty construction than to defects in the stone. Much of it was split into slabs and placed on edge, a position which results in more extensive spalling than when blocks are placed with the bedding horizontal. The stone is still quarried and gives excellent service if properly placed in the wall.

Idaho.—Medium-grained light-buff and also fine-grained gray sandstones are quarried on Table Rock near Boise in Ada County. They are used for local building in Boise and are shipped to Colorado, Oregon, and Washington.

Indiana.—A sandstone quarry has been worked for several years in northern Orange County, a few miles south of Mitchell. It is reported that wire saws are used quite successfully in this deposit. Sandstone for abrasive purposes is quarried at Floyds Knobs, Floyd County. Orange County was at one time a source of considerable quantities of whetstones. Building sandstone is quarried also at St. Meinrad, Spencer County.

Kentucky.—In Kentucky the most important deposits are at Bluestone and Farmers, Rowan County, and Wildie, Rockcastle County. The Rowan County stone is very fine-grained and takes an excellent sand-rubbed finish. It is sold as sawed and cut stone for building purposes, finer grades being used for mantels and other interior work. Kentucky and near-by Ohio, especially Cincinnati, are the chief markets, though some of the stone is shipped to distant cities. The Rockcastle County stone was used chiefly for trimming, such as sills, caps, and copings, but quarrying has been discontinued.

Massachusetts.—Triassic sandstone similar to the Portland (Conn.) stone, ranging from red to brown, has been quarried extensively for building purposes at East Longmeadow, Hampden County. Although it is durable if used properly the stone has been in less demand during recent years.

Michigan.—Grindstones are manufactured at Grind Stone City, Huron County.

Minnesota.—The most important sandstone-quarrying region in Minnesota is at Sandstone, Pine County. For many years the Kettle River quarries at this place have produced an even-grained stone of light-pink to yellow or brownish-red color. It is probably of Keweenawan age. Quartz is the cementing material, and the grains are cemented so firmly that the rock approaches quartzite in texture. On this account

it is well-adapted for paving stones for which it is chiefly used. It has also been employed quite extensively for interior and exterior building, also as flagging and rubble and to a limited extent for furnace lining.

In southwestern Minnesota the Sioux quartzite of Huronian age is prominently exposed in Rock, Pipestone, and Nicollet Counties. The rock is extremely vitrified, having the appearance of massive quartz. It is red and makes a very beautiful, durable building stone; however, on account of its extreme hardness it is not used extensively. During recent years material quarried at Jasper, Rock County, has been used extensively to line tube mills and as grinding pebbles. For the latter use it compares favorably in service with Danish flint pebbles.

Associated with the quartzite in Pipestone County is a bed of an interesting red mineral called "catlinite" or "pipestone." This material is described more fully on pages 343 and 344.

New Jersey.—Sandstone has been used extensively for bridge construction in New Jersey. Recent production for various building purposes has been confined chiefly to Raven Rock, Hunterdon County, and Wilburtha, Mercer County. Argillite occurring in Mercer and Huntingdon Counties has been used for construction of many buildings in and about Princeton.

New York.—Several types of sandstone occur in New York. The largest quarries are in the Medina formation, Orleans County. This stone was formerly used to a considerable extent for building, but the chief output now is for paving stones and curbing. Both red and gray stones occur; the former is very attractive for building, and the latter is best adapted for paving. Because the rock is very resistant to abrasion it gives good service on streets having heavy traffic. Large quarries are, or have been, worked at Albion, Holley, Hulberton, Medina, and other places in Orleans County.

The sandstones most widely used in this State are the so-called "bluestones" of Devonian age, which occur chiefly along the Hudson River in Albany, Green, and Ulster Counties and along the Delaware River in Sullivan, Delaware, and Broome Counties. Other outcrops are in Wyoming County and in the counties bordering Pennsylvania westward from Chemung. Typical bluestone is an argillaceous sandstone, which is usually dark blue-gray. It occurs mostly in thin beds and splits readily into smooth, uniform, thin slabs. Thus, it is particularly useful for flagging, curbs, sills, caps, and steps. The annual sales value of bluestone for the entire State is about three-quarters of a million dollars.

Red Potsdam sandstones have been quarried in the northern Adirondacks for building purposes, but none of the quarries are now in operation. At times small quarries are operated in various parts of the State, mainly for special jobs, but they are not regular and consistent producers.

Ohio.—Just as Indiana is the leading producer of block limestone so Ohio leads in sandstone, producing between 50 and 60 per cent of the total output for the United States. Extensive deposits of Mississippian (lower Carboniferous) age appear in a broad belt which extends from Portsmouth on the Ohio River in the southern part of the State almost due north to Norwalk, Huron County, and from there eastward to the northeastern corner of the State. Except near South Euclid the lower member, the Bedford stratum, contains little sandstone of commercial value. The largest quarries in Ohio are in the Berea formation, which

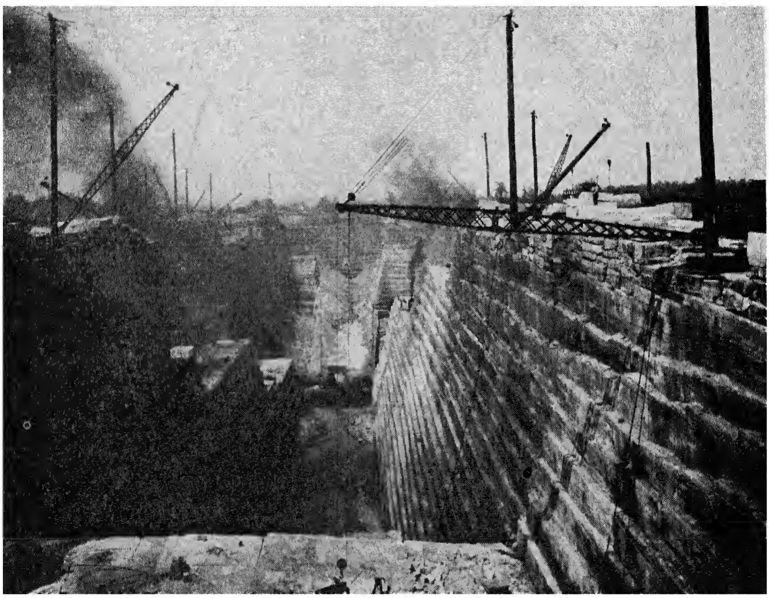

FIG. 12.—A large sandstone quarry near Amherst, Ohio. (*Courtesy of The Cleveland Quarries Company.*)

lies above the Bedford. The Cuyahoga formation, which lies above the Berea and is separated from it by the Sunbury shales, is quarried in Scioto County, southern Ohio. Pennsylvanian (upper Carboniferous) sandstones outcrop throughout the eastern third of the State except in the north, and are quarried in many places. The largest quarries, one of which is shown in figure 12, are near Amherst, Lorain County, where the rock lies in horizontal beds which were once the shore cliffs of Lake Erie. The sandstones are fine- to medium-grained and are blue, gray, buff, and variegated. Complete oxidation of impurities as a result of high elevation has given a stable buff coloration to the upper beds. The rock varies considerably in character from one bed to another, and each bed may show adaptability for some particular use. Thus, at different levels stone is obtained for building, for bridge con-

struction, for curbing, flagging, and rubble, or for grindstones. The buff and variegated stones are used both for exterior building and for interior work in office buildings, churches, and residences. Much of the building stone is sold in rough or sawed blocks. Differences in texture have given rise to various local terms. An evenly stratified stone that splits well is called "split rock"; rock of irregular stratification, marked by fine transverse and wavy lines, is called "spider web"; and massive

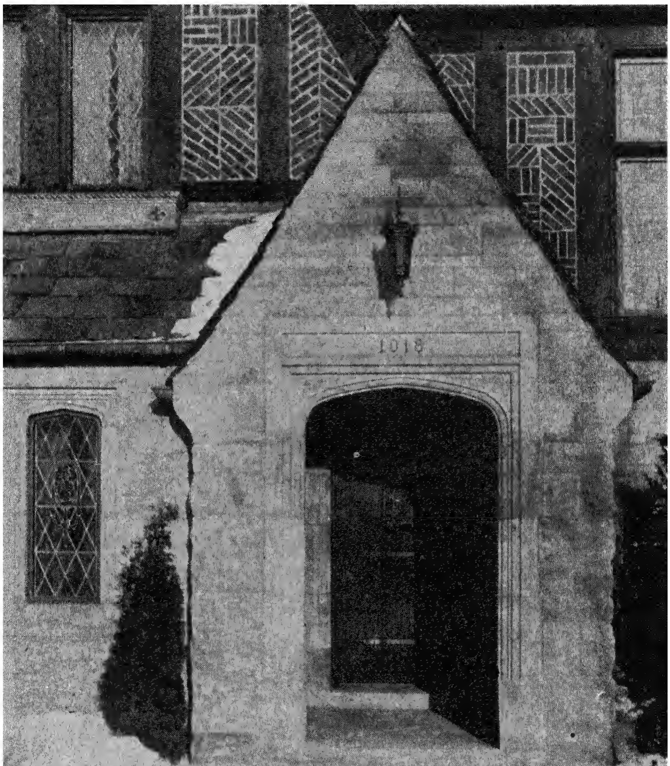

Fig. 13.—An attractive use of sandstone ashlar. (*Courtesy of Briar Hill Stone Company.*)

stone which shows no evidence of stratification is termed "liver rock." The Amherst rock contains about 95 per cent silica; the remainder is made up principally of lime, magnesia, iron oxides, and alumina. To avoid injury to the stone through freezing of the quarry water, the quarries are operated only about eight months in the year.

The quarries near Berea, Cuyahoga County, are about 40 feet deep. The stone is a little darker than the principal products at Amherst and is adapted chiefly for building, grindstones, curbing, and flagging. "Euclid bluestone," quarried near Euclid in the same county, is finer-grained than the Berea stone and must be selected carefully because

of the common occurrence of pyrite crystals. It is sawed for flagging, steps, caps, sills, and laundry tubs.

Sandstones from near Empire, Jefferson County, and at Constitution and Marietta, Washington County, are used chiefly for grindstones and pulpstones. A fine-grained sandstone from McDermott, not far from Portsmouth, Scioto County, is quarried for a great variety of uses, including interior and exterior building, burial vaults, grindstones, flagging, and many small abrasive stones, such as hones and whetstones.

Sandstone quarried near Killbuck, Holmes County, is widely known as "Briar Hill" stone and is popular for building purposes on account of its variegated colors. The quarries are situated at a high level, and the stone is brought down by cable cars. Production, chiefly of dressed building stone, has increased greatly during recent years. Its use as ashlar in home construction is shown in figure 13.

A quarry at Sherrodsville, Carroll County, produces sandstone which is sold chiefly as sawed and dressed building stone. Sandstone for rough construction is obtained at Lisbon, Columbiana County, and both curbstones and rubble are manufactured at Youngstown, Mahoning County. Other quarry locations are Sugar Grove and East Lancaster, Fairfield County, and Kipton, Lorain County.

Ohio building sandstone is marketed throughout the Middle West and even in eastern cities. Most of the other products are distributed even more widely.

Pennsylvania.—Sandstones are widely distributed in Pennsylvania and are of many different types. Carboniferous sandstones and quartzites appear in many places. Triassic sandstone quarried at Waltonville, Dauphin County, was sold in past years as a building stone under the name "Hummelstown brownstone," but the quarries are now idle. Much material has been quarried for bridge work and other heavy construction; Curwensville (Clearfield County), Koppel (Beaver County) and Ellwood City (Lawrence County) are noteworthy centers of the most recent production. Sandstone for rough construction is quarried at Avondale, Chester County. A very attractive variety for interior and exterior construction occurs at Waynesburg, Greene County, in the extreme southwestern part of the State. Many small quarries produce rubble, rough building stone, curbing, flagging, and paving blocks. Devonian bluestones similar to the occurrences in New York are quarried, principally along the bluffs of the Delaware and Susquehanna Rivers in northeastern Pennsylvania. Some of the more important production centers are Pond Eddy and Kimble, Pike County; Alford and Stevens Point, Susquehanna County; and Meshoppen, Wyoming County. A stone ranging from a quartzite to a quartz-sericite schist is quarried near Edge Hill, Montgomery County, for building stone and as a refractory for furnace lining.

South Dakota.—Sandstone for building purposes has been produced for many years near Hot Springs, Fall River County. The Sioux quartzite is quarried as building stone near Sioux Falls, Minnehaha County. The deposit is continuous with that quarried at Jasper, Minn.

Tennessee.—A thin-bedded quartzite occurs near Crab Orchard and Crossville, Cumberland County. The rock splits into remarkably uniform slabs ⅜ inch to 15 inches in thickness and is noteworthy for its adaptability. The thin slabs may be used for roofing; thicker slabs for floor tile, flagging, and steps; and the heavier beds, for building stone. For many years it has been quarried in a small way, but the industry expanded considerably in 1929 and 1930.

Virginia.—Sandstone of Triassic age was quarried many decades ago at Aquia Creek, Stafford County. It supplied stone for the United States Capitol, the White House, Patent Office, and other buildings in Washington. The quarries were idle for many years but were reopened and have provided a substantial supply of building stone for use in Washington and other cities. The rock is light gray, streaked or clouded with buff, yellow, or red,—combinations that are popular with architects. Similar rock was quarried many years ago near Manassas, Prince William County.

Washington.—Sandstone development in Washington has been confined largely to regions having efficient means of transportation. Pierce and Thurston Counties have the most available occurrences. At Wilkeson, Pierce County, a medium-grained gray sandstone is quarried for local use and for shipment to near-by States. It is sold as cut stone, sawed stone, rubble, paving blocks, and pulpstones. Stone which is dark gray at depth and dark or light buff above ground-water level is quarried at Tenino, Thurston County, and used for building purposes in Washington, Oregon, Idaho, and California. Abrasive stones known as "holystones" are at times manufactured from Tenino sandstone.

West Virginia.—Sandstones are abundant in West Virginia and represent many geologic formations. A quarry in the Saltsburg sandstone at Kingwood, Preston County, has furnished good-quality building stone for use in New York, Philadelphia, Washington, and other eastern cities, but very little has been produced since 1914. Grindstones and pulpstones are produced near Ravenswood, Jackson County, and near Fairmont, Morgantown, Opekiska, and Uffington, Monongalia County.

Wisconsin.—A belt of Potsdam (Cambrian) sandstone, known as "Lake Superior brownstone," skirting the southern shore of Lake Superior has been quarried chiefly at Port Wing, Bayfield County, but there has been little recent activity. The stone is a coarse-grained, reddish-brown material that has been used in Wisconsin, in near-by States, and to some extent in Canada. In the west-central part of the State, chiefly in Dunn County, a southern belt of the Potsdam sandstone

also provides commercial stone. Fine-grained cream-colored and buff stones, marketed under the trade name "Dunville Stone," are used for exterior building purposes for entire structures or as trimming of schools, churches, and other public buildings throughout the Middle West and to some extent in the East. Rock for rough building stone, paving blocks, curbing, and rubble is quarried in various other parts of the State.

QUARRY METHODS

Influence of Induration.—As previously stated, the workability of sandstones probably varies more than that of all other common rocks, owing mainly to the condition of cementation of constituent grains. The degree of cohesiveness may range from loose and friable types to indurated quartzites. Quarry methods are governed largely by workability. For example, highly indurated sandstone can not be channeled but must be blasted, with the probable result that much of it will be shattered and wasted, whereas a soft rock may be cut into rectangular blocks with a channeling machine, and the waste will be much less. Quarry costs per cubic foot are usually much higher in the harder rocks.

Influence of Rock Structures.—Rock structures that have a predominating influence on quarry methods are joints, bedding seams, rift, reeds, and run.

Joints.—Natural open seams or joints presumed to originate mainly through compressional or torsional earth strains characterize most sandstone deposits. In flat-lying deposits they are usually perpendicular to the bedding and hence are vertical, or nearly so. They generally occur in two or more systems, the joints of which approximately parallel each other. When occurring in two vertical systems at right angles and spaced 10 to 40 feet apart, they greatly facilitate quarrying.

To promote economy, quarry walls are maintained parallel with the major joint systems. Thus, joints may be utilized to take the place of openings that must otherwise be made by channeling or blasting. The term "cutter" is generally applied to closed or inconspicuous joints, sometimes called "blind seams" or "closed seams." Usually they are planes of weakness that must be avoided in dimension stone.

Bedding Seams.—Open seams parallel with the bedding occur commonly in sandstones and usually are of great advantage in quarrying. If they are present at intervals of a few inches to 3 feet apart, the deposit is described as "thin-bedded"; if at intervals of 10 or 15 feet, it is "thick-bedded"; rock in massive form with no open bed seams is "tight-bedded." Deposits near Amherst, Ohio, are of the latter type.

Most sandstone quarries are situated in horizontally bedded deposits. Such flat-lying beds afford the simplest type of quarrying. The Potsdam sandstone of northern New York is an exception, as the beds dip 20 to 25 degrees, but very little quarrying is now carried on in this rock.

Rift.—Rift is the plane of easiest splitting in sandstone; almost without exception it parallels the bedding. It is a variable property; some beds split with the utmost ease, whereas others have so poor a rift that the rock splits in other directions almost as easily as it does parallel with the bed. Such rocks are said to be lacking in rift. Rift is due chiefly to orientation of grains. The presence of flaky minerals like mica or clay may increase the rift, for in the process of sandstone deposition such grains tend to come to rest horizontally, parallel with the bedding. In like manner, other mineral grains tend to have their long axes parallel the bedding plane, and this parallelism increases to a marked degree the ease of splitting.

Rift may vary greatly in successive beds of a deposit. In the Amherst (Ohio) quarries the "split-rock" beds have excellent rift, which gives smooth uniform surfaces. In "cross-grained" beds the rift is difficult and uncertain; it may slant at abrupt angles to the general bedding plane. The "liver rock" has a massive structure with no indication of bedding and consequently lacks rift.

In quarrying, a good rift assists greatly as it facilitates bed lifting where open bed planes are absent. Ease of splitting and the smooth surfaces obtained are also of great advantage in subsequent operations of shaping blocks into various finished products in the mill or yard.

Reeds.—The rift may not be the same in all parts of the same bed; that is, the rock may split much more easily along certain planes than along others. This may be due to a change in sedimentation, such as the deposition of a thin layer of foreign material, as clay, to which the sand grains above and below do not adhere readily. Again, it may be due to a pause in the process of deposition with a smoothing over of the surface and a filling up of the irregularities that are essential to a condition of relatively high cohesion perpendicular to the bedding plane. It may also be due to parallelism of grain orientation in certain zones. Such planes, along which the rock tends to split with greater ease than in intermediate planes, are termed "reeds." They are characteristic of many bluestone deposits. The quartzites near White Haven (Pa.) split easily along reeds marked by fine white lines and with difficulty in intermediate positions. Like rift, the reeds are very helpful in separation of blocks.

Run.—The term "run" is applied to a second direction of easy splitting less pronounced than rift. It is also called the "breaking way" or "grain," though the term "grain" is used by some quarrymen as a synonym for rift. Usually the direction of run is perpendicular to the rift, and therefore in flat-lying beds the run is in some vertical plane, since the rift is horizontal. Bownocker[10] states that from Berea to Berlin Heights, Ohio, the run is nearly east and west—that is, it parallels the

[10] Bownocker, J. A., Building Stones of Ohio. Geol. Survey of Ohio, ser. 4, Bull. 18, 1915, p. 111.

old shore line. Run is probably due to orientation of minerals and in the above locality prevailing ocean currents at the time of deposition may have arranged the minerals with their long axes parallel to a particular direction of the compass. In some sandstone deposits a distinct run is recognizable and is of considerable advantage in giving smooth, straight, broken surfaces or in permitting wide spacing of drill holes for blasting or wedging. In other deposits it is absent or is so indefinite that it exerts no apparent influence on quarry processes.

Quarry Methods in the Softer Sandstones.—By far the larger part of the sandstone produced in the United States is from the softer types of moderately easy workability. Channeling machines may be employed in such stone, the extent of their use depending mainly on joint systems. Where few joints are found it may be necessary to channel all wall cuts and whatever other cuts may be required for separating the larger masses of rock, except where an occasional joint may be utilized. The larger quarries in northern Ohio are of this type. If joints are in one parallel series, spaced 20 to 50 feet apart, it may be necessary to channel wall cuts only along the side at right angles to the joints. These are called "back-wall cuts." Where joints are in two intersecting systems, meeting approximately at right angles, channeling may be required only for the removal of key blocks. In deposits where joints are more closely spaced, channeling machines may not be required, the necessary breaks being made by blasting or wedging. An effort is always made to work into such deposits in the direction of convergence of the joints in order that blocks may be removed without binding against walls. Sandstone deposits near Springfield, Mass., and Hummelstown, Pa., are of this type. Wire saws, described in a later chapter on slate, are used to a limited extent as substitutes for channeling machines.

Quarry methods are influenced greatly by the nature of the bedding. In massive, tight-bedded deposits floor breaks must be made by wedging, and in heavy-bedded deposits like those at Berea, Ohio, large masses are channeled and subsequent breaks made with black-powder shots. Channeling usually is required only for wall cuts in thin-bedded deposits, and wedging generally is better than blasting for further subdivision because straighter breaks may be made and less waste results. Deposits of this kind occur near South Euclid, Ohio, and Farmer, Ky. A good rift greatly assists quarrying and is especially advantageous in tight-bedded deposits where floor breaks are required. If the rift is good, a mass of stone 12 to 15 feet wide may be lifted by wedging, whereas, in a "liver rock," beds are rarely lifted in widths of more than 5 or 6 feet.

Quarry Methods in Indurated Sandstones.—As a rule, sandstones sufficiently indurated for good paving blocks are too hard to be channeled economically, and blasting or wedging must be substituted. Quarrying in such deposits is therefore more complex and costly than in the softer

types. Even in some hard rocks channeling machines are used for wall cuts because much shattering results from blasting if only two free vertical faces are present. In best practice, quarry walls are maintained parallel with the major open joints, which are utilized wherever possible instead of channel cuts. Larger masses are subdivided by separating along bed planes and making cross breaks by wedging in drill holes in directions of rift and run, if such are present. Easy splitting of beds and conveniently spaced vertical open joints are favorable structural features.

QUARRY PROCESSES

Channeling. *Rate of Cutting.*—When sandstone was first quarried in the United States channels were cut with hand picks wide enough to admit the body of a workman. About 1880 this slow, wasteful method was superseded by steam-driven channeling machines capable of making cuts 6 inches wide or less. Channeling machines of the steam, electric, and electric-air types similar to those described in the preceding chapter on limestone are now widely used. The rate of cutting depends on the condition of cementation of the rock and ranges from 100 to 500 square feet a day. If hard, flinty masses are encountered the rate will be diminished temporarily, and the channel cut may be diverted from its straight course. Usually the average rate of cutting is much less than the maximum rate of which the machine is capable, because heavy blows struck by channel bars when a machine is driven at its maximum capacity tend to shatter or "stun" the rock. "Stunning" is a quarryman's term for the production of impact fractures that may extend a foot or more into the rock and thus waste otherwise good stone.

In terminating a channel cut in solid rock the cutting out of the lower corner to give a vertical end is slow and tedious, but sometimes is greatly facilitated by sinking a 4-inch vertical drill hole at the place where the cut is to end.

Wear on Steel.—Channeling in sandstone is quite different from that in limestone or marble. Although the rate of cutting may be much faster the steel wears much more rapidly on account of the abrasiveness of the sand grains. In the quarries of northern Ohio the machine usually works back and forth on a cut about 30 feet long, and for such a cut the steel must be changed about every 18 inches of depth attained because of the loss in gage from wear. The first set of bars makes a cut about 4 inches wide, and each successive set must be narrower than the preceding to avoid binding. Until recently cutting was done dry as the steel wears more rapidly if water is added. One or two men were employed at each machine to scoop out the sand cuttings, which in soft sandstone amounted to several tons a day. Wet methods are now used.

Maintaining Minimum Number of Channel Cuts.—Channeling is more expensive than blasting or wedging per square foot of surface obtained

and therefore is employed only for wall cuts, for separation of key blocks, and for whatever other cuts may be necessary to prepare a block or mass of stone for wedging or blasting. The latter processes are very ineffective or wasteful unless the mass to be separated has five free faces, leaving only one to be broken free. Thus, the mass of stone shown in figure 14 had only four free faces before channel cut "x" was made, namely, the two sides, front, and top, and therefore, it could not be wedged or blasted effectively. After cut "x" is made it is fast at the floor only and therefore has five free faces. A floor break, "a," may be easily made by wedging, and the block may be subdivided further by wedging or blasting at "b." For this and each subsequent break there will always be five free faces. Quarrying should be so planned that the least possible channeling may be done to attain favorable wedging or blasting conditions. Vertical joints may be of great assistance in obtaining the necessary number of free faces. It is also obvious that open bedding planes or a good rift will reduce the number of channel cuts.

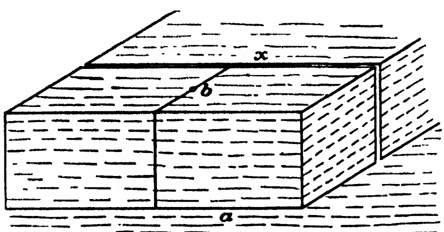

FIG. 14.—Separating blocks with five free faces. *x*, channel cut providing fifth free face; *a*, first break; *b*, second break.

Direction and Spacing of Cuts.—Channel cuts should parallel or be at right angles to the major jointing systems. The spacing of channel cuts should be governed by the size of quarry block desired; that is, the number of feet between cuts should be multiples of the final quarry-block dimensions.

Drilling. *Machinery.*—Tripod drills, bar drills, and hammer drills are the chief types used. The first is a reciprocating drill mounted on a tripod, and the second is a similar drill attached to a horizontal bar supported by four legs. The tripod must be moved to a new position for each hole drilled, but a line of holes may be drilled from one position of the bar, the drill being moved along and clamped successively in new positions. Bar and tripod drills usually are operated by steam. A hammer drill is a nonreciprocating impact drill with an automatic rotating device. It employs hollow-steel drill bits through which the exhaust air passes and blows the cuttings from the hole. It is usually unmounted, is held in position by a handle bar, and may be moved with very little loss of time. This offers certain advantages, particularly in thin-bedded rock where holes are shallow and frequent moves are necessary.

Compressed air generally is preferred to steam for quarry drilling, particularly in cold climates where the condensation loss of steam is heavy. Moreover, when steam drills are used water must be supplied

to remove the cuttings, which necessitates extra labor and makes a wet or muddy floor.

Drill Steel.—Drill steel should be of a consistency that will withstand excessive abrasion. Efficiency in drilling depends largely on the shape of the bit. As narrow wings wear away quickly the drill head is shaped to keep as much steel as possible near the circumference of the bit. Most sandstones cut rapidly, therefore drill bits must have grooves large enough to provide easy clearance for cuttings. Some drillers prefer square bushings to hexagonal, as they do not wear off so quickly.

Rate of Drilling.—The rate of drilling varies with the hardness of the stone; 1 foot in 38 seconds for a $1\frac{3}{4}$-inch hole has been recorded in a northern Ohio quarry. Holes of $\frac{1}{2}$ inch diameter were drilled in White Haven (Pa.) quartzite at a rate of 3 inches in 35 seconds, a much slower rate for holes of very small diameter.

Circle-cutting Drill.—In some localities where grindstones or pulpstones are made, rectangular blocks are scabbled to a circular shape. In southeastern Ohio it has been found more convenient and less wasteful to cut out circular blocks in the quarry with a machine known as a "ditcher" or "circle-cutting drill," which is supported by tripod legs and a vertical bar which fits into a 4- by 4-inch square hole in the surface of the rock. The drill is attached to one end of a heavy crossbar, with a counterbalance weight at the other end, and is rotated by a worm gear. By securing the drill in different positions on the bar the diameter of the circle to be cut may be varied. In cutting a circle 7 feet in diameter the steel is changed about every 6 inches in depth, and each successive drill bit is about one-fourth inch smaller to allow for loss in gage by wear. A four-pointed star-shaped drill head is used. If cuts run from their true course, as, for example, at the point where they meet other cuts, a sharp-pointed bar is used to trim and straighten them. It is claimed that a ditcher will cut as many square feet in a day as a channeling machine, and much less time is required to set it up, as no tracks are necessary.

When a circular cut is completed a drill hole for the floor break is made by means of an air drill which slides on a horizontal bed. The drill is held in proper position and advanced by means of a hinged handle and crossbar.

Blasting. *Explosives.*—Black powder is used almost invariably for blasting dimension sandstone because dynamite unless of very low grade, gives a sudden and violent explosion, thus shattering the rock too greatly. Just enough powder should be used to make the fracture, and no more.

Knox System of Blasting.—The Knox system has two essential features—a grooved drill hole and an air space above the charge. Holes are drilled nearly to the bottom of beds and reamed or grooved with a flanged tool driven into the hole by sledging or operated as a drill bit

with the rotating device of the drill thrown out of gear. The grooves, about one-fourth inch in depth and on opposite sides of the drill hole, are made exactly in line with the direction along which the break is to be made. A small charge of black blasting powder is added, and a plug of cotton waste or other suitable material is placed in the hole some distance above the charge. The hole above the plug is filled with sand or other stemming. When an air space is thus provided the force of an explosion is exerted over a relatively wide surface and causes less shattering of rock than when the intensity of the force is localized in one spot. Moreover, the explosive force, as it enters the grooves formed by the reamer, tends to give a straight break. In the heavy-bedded rock

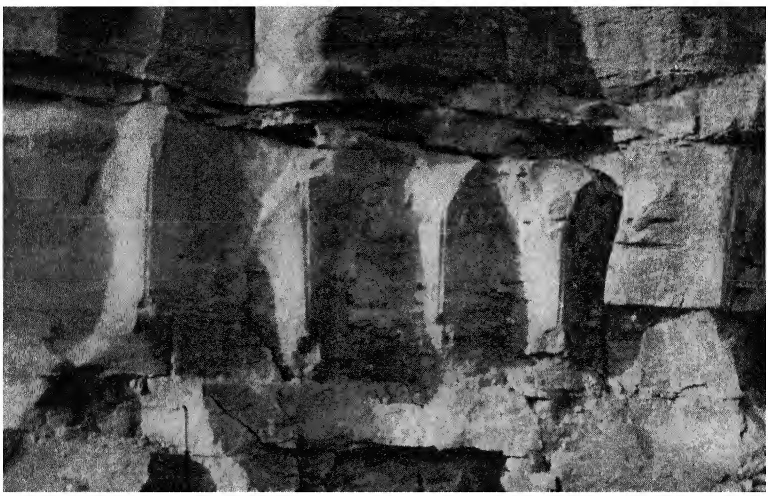

FIG. 15.—Uneven sandstone surface resulting from a break oblique to the "run."

near Berea, Ohio, the system is modified by leaving air spaces above and below the charge.

Methods of Shot Firing.—For single shots either a fuse or an electric firing machine may be used. Where a number of drill holes are to be fired at once electric firing is necessary and may be done with a hand-operated machine or by connection with the quarry current.

Arrangement of Drill Holes.—Holes for bed-lifting are drilled in line with the bedding planes or rift. If the rock has a pronounced "run," as described earlier, vertical breaks are, in best practice, made in line with it. If breaks are made oblique to the run two disadvantages are entailed. First, the rock splits with greater difficulty, and holes must be closely spaced; and second, a very uneven surface is obtained. Figures 15 and 16 illustrate the contrast in surfaces obtained in making breaks oblique to the run and parallel with it.

Blasting for Subdivision of Larger Blocks.—The preceding discussion of channeling and blasting relates almost entirely to separation of larger

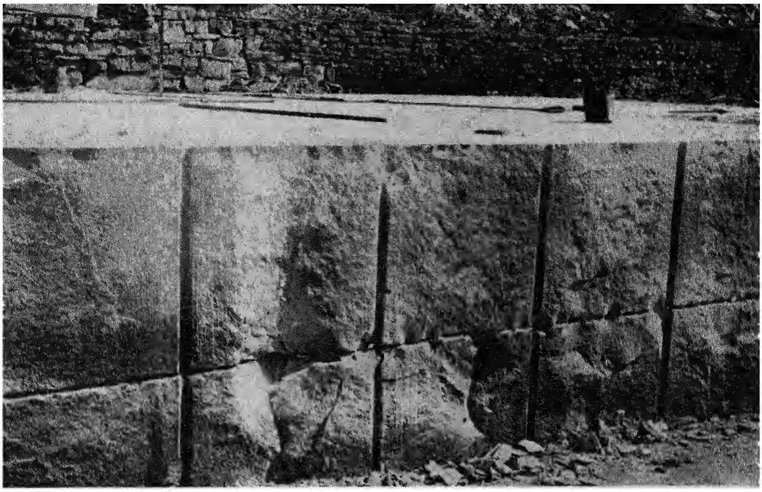

FIG. 16.—Smooth sandstone surface resulting from a break parallel to the "run."

rock masses from solid ledges. These masses usually are subdivided by blasting in heavy-bedded rock and by wedging in thin beds. It is a generally recognized principle that the blast should be centered; that is, an equal mass of rock should be on each side of the line of fracture. If drill holes are so placed that the rock mass is not balanced properly, the break tends to run toward the lighter mass. Therefore, the process of separation is a halving of the masses successively until blocks of the desired dimensions are obtained.

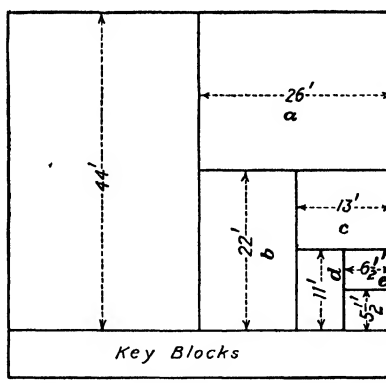

FIG. 17.—Method of subdividing blocks in an Ohio sandstone quarry. Breaks are made in the order of lettering, *a, b, c, d, e*.

The procedure in an Ohio quarry illustrates a typical process of subdivision. As shown in figure 17, the primary masses are 44 by 26 feet. Fractures made by blasting are shown by small letters. The shots are discharged in order of lettering, *a, b, c, d, e*. The final subdivisions give a series of blocks 6½ by 5½ feet, a size most convenient for curbing and flagging. This indicates the foresight necessary in selecting for the larger masses dimensions suitable for economical subdivision.

In rock with a pronounced run most subdivisions may be made by blasts in single, centrally located, drill holes. If the break is inclined

to the run, or if the run is poor, more than one blast hole may be required. Shots in single holes are commonly used for breaks up to 15 or 20 feet long. If the mass to be separated is more than twice as long as it is wide it is advisable to use at least two holes, which should be so arranged that the center space is a little more than twice as long as the end spaces. If the mass to be broken off is a small part of a much larger mass, the break tends to curve at the ends and slant toward the lighter part. This tendency may be overcome in some measure by blasting in two drill holes with a relatively long center space between.

Wedging. *Operations in Which Wedging Is Employed.*—Bed-lifting and subsequent separation of blocks on the bed or rift are accomplished almost exclusively by wedging. Vertical breaks are made by wedging, except in heavy-bedded rock, where blasting usually is employed.

Type of Wedge Employed.—For wedging in drill holes quarrymen use the "plug-and-feather" type of wedge described in the chapter on limestone. Wedges are of different lengths to accommodate them for use in deep or shallow holes. Blunt-steel wedges used without feathers are employed for driving in notches. A small steel wedge that tapers to a thin edge is known as a "point." This term is applied also to a tool having a pyramidal point used in finishing the surface of stone. A short, blunt wedge with a rectangular sledging face and triangular cross section is known as a "bull wedge."

Use of Wedges in Bed-lifting.—In tight-bedded deposits, when by means of channel cuts or open joints four free vertical faces are provided for a large mass of stone, the next step is to free this mass from the quarry floor. As the bedding in most sandstone quarries is horizontal, this process of separation is known as "bed-lifting," and the breaks are called "floor breaks." Wedges are used very generally for bed lifting. Ease of splitting depends on the rift, but breaks are so easily made in almost any sandstone that drill holes are unnecessary. In their place notches are cut into the face of the rock by means of hand picks. The notch is known locally as a "grip" or "side shear." Its lower face is horizontal or has a slight upward slant; and the upper face slants sharply downward, forming a V-shaped cut several inches deep. A sharp steel pick is used to finish the grip to bring it to a sharp point; otherwise, the end of the wedge would strike against the solid rock and fail to exert the desired effective upward and downward pressure. Blunt wedges are placed in the grip and driven with sledges. In hard-splitting rock or in making an excessively wide break wedges may be placed almost touching each other. Occasionally grips are cut on two faces, and the mass is raised by simultaneous wedging at the side and end.

In making floor breaks for large, circular masses cut out for grindstones, wedging in a grip is supplemented by wedging in a single drill

ɔle 4 or 5 feet deep passing under the center of the stone. A long edge with feathers attached to its extremity is inserted in a drill hole. ⁷hen it is driven between the feathers the lifting force is exerted near the ɔttom of the hole.

Wedging for Subsequent Breaks on Bed.—The softer sandstone blocks ay be split on the bed by cutting grip holes and driving points in them. ı easy-splitting rock they may be placed 1 to 2 feet apart; in tougher ›ck they may be placed close together in a continuous grip.

In the more indurated sandstones pick holes can not be cut readily. ı some quarries it is customary to place a block on edge and split it by edging on a "sett"—a quarryman's term for a square-faced steel tool ɘld in position by means of a handle. The block is marked at the ends ıd struck successive blows along the line of desired splitting until a acture is made. Quartzites are usually split by wedging in shallow drill ɔles.

Wedging for Vertical Breaks.—In quarries which have open bedding lanes spaced at distances of 5 feet or less, wedging may be largely ıbstituted for channeling, channel cuts being made only where clearance required. If possible, such breaks should be made parallel with the ın of the rock. In some northern Ohio sandstone quarries for making a ·oss break in a mass of stone 4 to 5 feet thick quarrymen first drill a ›w of holes 18 inches apart. Every third hole is made 4 feet deep and ırger than the others, which are 2 feet deep. Plug-and-feather wedges ·e placed in the holes and sledged in succession, beginning at one end the line, one blow being given to each of the smaller and two blows to ıch of the larger ones. Sledging is continued back and forth along the ne until a fracture appears. Breaks thus made may be 80 or 100 feet ›ng and 20 to 40 feet back from the face. For thin beds, shallow holes :e adequate.

In heavy beds with a poor run, deep-hole wedging is employed. hus, for a bed 5 feet thick holes may be made 4½ feet deep and 1½ to ½ feet apart. Holes of this depth are usually about 1⅞ inches in iameter at the top and 1¾ inches at the bottom and are drilled exactly ı the same plane. To assist in producing a straight break in tough rock channel about 2 inches deep is cut with hand picks across the rock ırface in line with the drill holes. Occasionally the holes are reamed, s in the Knox system of blasting. For deep-hole wedging the long lugs and feathers used are so constructed that when the plug or wedge driven the feathers are forced apart a uniform distance at all points ·om top to bottom. Thus the pressure is uniformly distributed throughut the full length of the wedge and is much more effective than when xerted at a single point or over only a small part of the drill-hole wall. 'urthermore, a wedge with a long taper exerts great force without heavy edging.

As soon as a fracture appears chips are broken out midway between drill holes, and blunt wedges are inserted. By sledging these wedges the pressure is relieved from the plugs and feathers, and they are removed. If the mass is not too heavy it may then be moved by steel bars which are inserted in the drill holes as levers.

In rock with a good run breaks up to 3 feet in thickness may be made in beds merely by driving points in a row of holes cut with hand picks. Even in tough rock small breaks may be made by cutting a continuous grip and driving wedges placed close together.

To assist in making straight breaks wedging is sometimes employed in conjunction with blasting. A powder charge is placed in a reamed

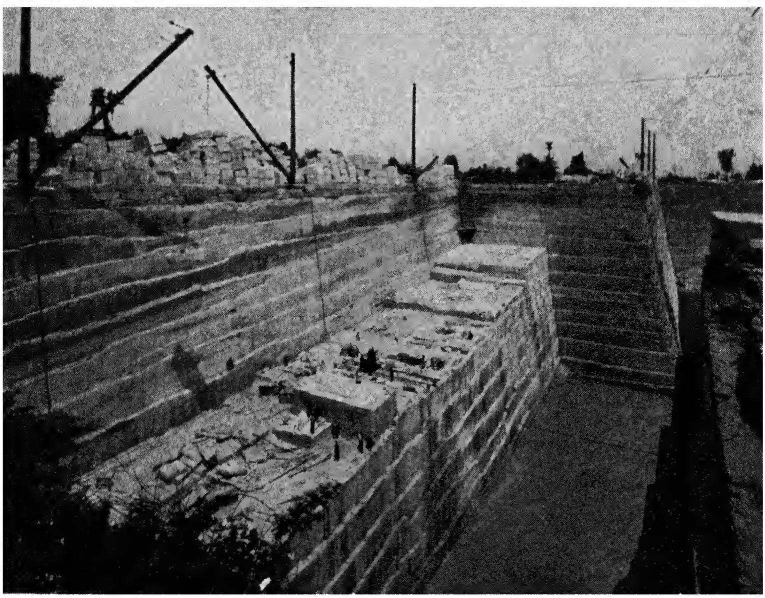

Fig. 18.—Arrangement of derricks for hoisting blocks from an Ohio sandstone quarry.

hole in the center of a mass of stone. Two wedge holes are drilled, one on each side of the blast hole midway between it and the edge of the block. Plug-and-feather wedges are driven into them until considerable strain is placed on the rock before the shot is fired.

Hoisting. *Equipment Used.*—Most hoisting at sandstone quarries is done with derricks consisting of a mast and swinging boom. Portable types are used for wide and shallow quarries where frequent moves must be made. A type of stiff-leg derrick used near McDermott, Ohio, may be moved to a new position in about two hours. When placed in position the base is loaded with blocks of stone to give it stability. For light hoisting a power shovel having a boom equipped with a running cable may be substituted for a derrick. Thus, power shovels which are used

for stripping operations in the winter and would otherwise be idle all summer are put to practical use.

Position of Derrick.—For large, deep quarries, such as those near Amherst, Ohio, many derricks arranged at regular intervals along the quarry bank are required. The mass of rock worked out from one position of a derrick is called a "motion." This includes the area covered by the radius of the boom together with that from which the rock may be dragged economically. The average area of a motion in one Ohio quarry is 134 by 61 feet. Figure 18 illustrates a ledge or bench and the series of derricks used to hoist the stone from it.

Cable Attachment.—Grab hooks, chains, and cable slings are used to hoist quarry blocks from the pit to the bank. Grab hooks are more generally used, for they have an advantage over other methods in that a block may be lifted from a flat position on a quarry floor, whereas chains or slings necessitate raising it several inches from the floor and blocking it up in order that the lifting apparatus may be passed beneath it. Shallow holes are made for the tips of the hooks. For hoisting heavy blocks two pairs of grab hooks may be used, one being attached near each end of the block. Some companies prefer chains or slings, as they are considered more secure than grab hooks. They may be left around blocks which are hoisted from a quarry and placed on flat cars for transportation to mill or yard. It is then a simple matter to hook into the chain for unloading, and much time is saved.

Pumping.—Some quarries of the hillside or shelf type are fortunate enough to have automatic drainage. Even pit quarries may in exceptional instances be underlain by permeable beds which permit water to drain away. In those that do not have automatic drainage, pumps must be installed. If only surface water enters a quarry little pumping is necessary, except in times of heavy rain or flood, but if springs are encountered the water has to be removed almost constantly. For shallow quarries with a drainage basin lower than the floor a siphon may be used if the lift is less than 30 feet. This method has been used at Hummelstown, Pa., and in a number of bluestone quarries. Piston pumps operated by steam, electricity, or gasoline engines, centrifugal pumps, and pulsometers are the types most generally used.

YARD SERVICE

Yard service relates to transportation from quarry banks to mills or finishing plants or direct to transportation lines where mills are not operated. It also includes transportation of finished mill products to railway lines or navigable waters over which they are carried to their destination.

If mills are close to quarries a yard derrick may take stone from the quarry bank and deliver it direct to the mill. If mills are at a distance

blocks are loaded onto cars for transportation. When finishing processes, such as shaping grindstones or splitting and trimming curbstones, are conducted outdoors, yard derricks may be employed to handle heavy rock masses. They are also used to load gang cars, to pile finished products in the yard, or to load them ready for transportation. A derrick with a boom which may be swung in a complete circle around the mast but can not be raised or lowered is convenient for handling material of small size. The boom is in the form of an I-beam, and a small traveling crane runs back and forth on it. In some places, locomotive cranes do the work of derricks. Overhead traveling cranes that are commonly used in mills may be extended to give yard service.

Transportation of rock from quarries to mills or from mills to shipping points may require cars and trackage. Haulage may be by gravity or by locomotives, cables, horses, or mules. Teams and wagons or auto trucks are also used.

SANDSTONE SAWMILLS AND FINISHING PLANTS

Mills Connected with Quarries.—Although large quantities of sandstone are sold to dealers or finishing plants nearly all quarries that produce building stone, grindstones, curbing, or flagging, except bluestone quarries, also operate mills or finishing plants. This association of activities has certain advantages. For instance transportation expense of waste rock is avoided, as it is left near the quarry; also the quarryman understands his rock and can work it most economically.

Mills usually are close to quarries. Even when quarries are at high levels—for example, those near Empire, Ohio—mills are at the same level, and finished products are brought down by cable cars. At Sherrodsville, Ohio, however, the quarry is at a high level, and the finishing plant is at the foot of the hill.

Sawing. *Gang Saws.*—Sandstone is sawed mostly with gang saws—iron blades set in a frame. Sand and water are fed to them as they travel backward and forward, and they cut by abrasion. Blocks of any width or slabs of any thickness may be obtained by merely adjusting the spaces between the blades. The frames are of various widths and lengths, depending on the sizes of blocks sawed.

Two types of gangs are in common use—the rope feed and the screw feed. The rope-feed gang is suspended by a steel cable attached to counterbalance weights. The weights may be so adjusted that the gangs can exert any desired downward pressure of the saws on the rock. Thus, constant pressure may be maintained, and the rate of cutting will be governed by the hardness of the rock. If a hard, flinty mass is encountered, the rate of descent is reduced automatically until the obstruction is cut through.

Screw-feed gangs are fed downward by gears, and although the rate of downward motion may be regulated, the device is not self-adjusting. If a flinty mass is encountered the rate of sawing is not automatically reduced, and if the saw is overcrowded the blade is inclined to run to one side, with consequent production of an uneven rock surface. The screw feed is employed on nearly all modern gangs.

The saw blades are carefully adjusted to run straight and true without any side motion, which may involve adjustment of shafts and bearings, as well as of the blades themselves.

Abrasives.—Silica sand is the abrasive used most commonly in sawing. It leaves a smooth surface and causes no staining of the rock. Although crushed steel and steel shot cut 25 to 50 per cent faster than sand under similar circumstances, they have some disadvantages. They leave a much rougher surface, and if the stone is to be used for structural purposes, sand-rubbing of the surface may be required, whereas if sand alone is used as abrasive this process may be omitted. If the stone is porous, stains may result from iron rust. Steel abrasive is satisfactory if the stone is to be used for curbing or flagging, as slight stains have little consequence. A mixture of sand and steel sometimes is used.

Sand Pumps.—Centrifugal sand pumps are commonly used for elevating the abrasive to a point above the gangs from which it may be distributed to the saws for repeated use. A belt with crossbars may be used to convey the sand to the pump well if the concrete bed beneath the gangs is too flat to return it automatically. In many mills an air lift is used. A well deep enough to have about one and a half times as much pipe submerged as above water level is required. A jet of compressed air entering at the bottom agitates and aerates the water, causing it to rise in the pipe and carry the sand with it. The great advantages of an air lift are its simplicity and the absence of moving or rotating parts, which are rapidly worn out by sand. At some mills pumps are not employed, the abrasive being shoveled by hand. Where river sand is obtainable near by, it may be allowed to escape after one use.

Rate of Sawing.—The rate of sawing sandstone blocks depends on a number of factors, such as length and number of blades, kind of abrasive and hardness of the stone. Gangs containing 10 to 15 blades saw average sandstone blocks 5 to 7 feet long at the rate of 3 to 8 inches an hour when sand is used, and 6 to 12 inches when steel is used. The rate also is governed by the nature of the product. For rough material, such as curbing, saws may be crowded to their maximum capacity, but when building blocks are being sawed this is not permissible, as it may produce irregularities on the surface. The more indurated sandstones can not be sawed profitably.

Gang Cars.—In old-fashioned mills timber beds were provided on which blocks were placed for sawing. The difficulty encountered and the

excessive time spent in loading and unloading the bed led to introduction of the gang car, which is simply a portable saw bed—a small four-wheeled car which runs on a track beneath the gang and is braced securely.

Transfer Cars.—In some mills much loss of time occurs in removing sawed slabs from gang cars and reloading them with blocks ready for sawing. To reduce the time in which the gang saw is idle the more modern mills are equipped with "transfer cars" which run on a depressed track in front of the gangs and are provided with a short section of track across the top. Thus, a gang car may be run from beneath a gang saw onto the top of a transfer car and removed very quickly. Another gang car loaded with a block of stone is held ready on a second transfer car, which may be shifted quickly into proper position in front of the gang-car tracks, and a new block is thus placed beneath the saws with little loss of

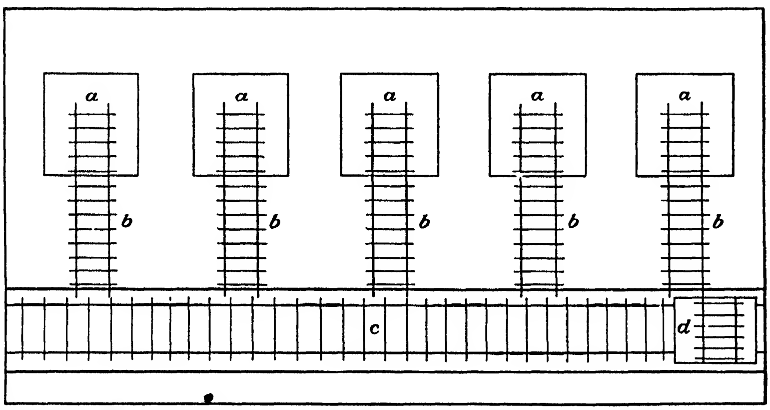

FIG. 19.—Arrangement of transfer and gang-car tracks in a sandstone sawing mill. *a*. gang saws; *b*, gang-car tracks; *c*, depressed transfer-car track; *d*, transfer car.

time. The track arrangement is shown in figure 19. At some mills gang cars are readily loaded and unloaded by derricks or overhead traveling cranes, and transfer cars are not used.

Other Types of Saws.—While gang saws generally are used for major cuts, smaller blocks and slabs are usually shaped with other types of saws. Circular saws with Carborundum teeth have given satisfactory service, even in hard sandstones. Blades mounted with diamond teeth and set in straightcut gang frames are used to some extent. Diamond circular saws have not given satisfactory service.

Wire saws are used for jointing sandstone mill blocks at McDermott, Ohio. Blocks are placed on the saw bed in piles about 10 feet wide and 4 to 12 inches high, and thus 12, or more are cut at one time. Sand is used as abrasive. The saw cuts downward by automatic feed at about 24 inches an hour. It cuts very effectively and to reasonably accurate dimensions with a tolerance of about one-eighth inch. Wire saws also

are used very effectively in northern Ohio sandstone mills. Clever adaptations have been devised for cutting rough columns and even for blocking out carved work.

Rubbing. *Nature of Process.*—Rubbing is the process of smoothing the surface of stone by abrasion. Exposed surfaces of structural blocks usually require such treatment. Where sand is used as the abrasive in sawing the resulting surface may be so smooth that rubbing will be unnecessary. However, where steel is used the surface usually is scratched and scored to the extent that rubbing is required.

Rubbing Beds.—A rubbing bed consists of a heavy iron disk 10 or 12 feet in diameter, which rotates in a horizontal plane. A block or slab of stone that requires rubbing is placed on the upper flat surface, and while the disk rotates the block is prevented from rotating with it. Sand and water are supplied, and the surface is rubbed or ground to desired smoothness and uniformity. Rubbing beds also are used for grinding blocks or slabs to accurate dimensions.

Reuse of Sand.—At some mills sand once supplied to rubbing beds is carried away without being reused. A more economical method is to return it to the bed until it is worn out. To accomplish this purpose the sand is washed to a sink in which the larger particles remain while the fines are carried away in the water. A bucket elevator or some other device is used to carry the sand to a point above the rubbing bed.

Planing.—Planers, chiefly of the Scottish reversible-head type, are used in shaping such forms as cornices, moldings, and curbstones. In planing the harder sandstones difficulty is experienced in getting a tool that will stand the work required of it, as the heat generated burns the steel. Overheating may be overcome by directing a heavy stream of water on the tool.

Manufacture of Curbing.—The manufacture of curbstones is an important part of the sandstone industry. The larger blocks usually are drilled and split into smaller sizes with plug-and-feather wedges. Final splitting into rough curbstones is accomplished in different ways, depending upon the ease of splitting. In "split rock" a series of notches are cut in line by means of a pick, the rock is then marked along the line with a chisel-edged tool and hammer, and the split is made by sledging bull wedges in the notches. In rock which splits with greater difficulty plugs and feathers may be used. Massive rock is sawed into curbing blocks.

Some Ohio mills are designed especially for manufacture of curbing. Planers are arranged in two parallel series with tracks between. The sandstone blocks are brought in on cars and transferred to the planers with overhead traveling cranes or pneumatic hoists. Finished curbstones are reloaded in the same way and conveyed from the mill for storage or shipment.

Manufacture of Grindstones and Pulpstones.—In southern Ohio the larger grindstones and pulpstones are cut in circular form in the quarry by means of circle-cutting drills, as described on a previous page. In northern Ohio they are quarried as rectangular blocks and scabbled to circular form. Stones thus roughly shaped are finished by cutting square-center holes, placing them on shafts, and turning them to true form with steel tools as they rotate. Both faces and sides are trimmed in this way. Figure 20 illustrates the method of shaping a 7-foot stone. The upright pins on the timber base are for the purpose of holding the cutting bar in various positions. A workman may stand on either side, and if two men are employed both sides of the stone may be trimmed

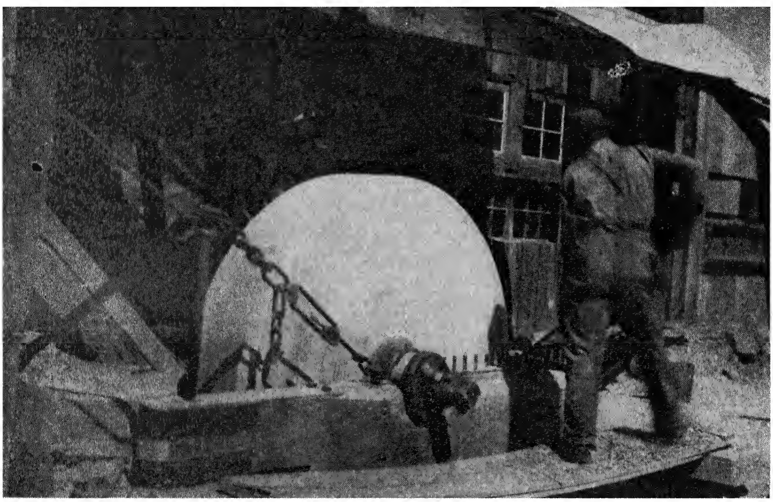

Fig. 20.—Method of shaping a large grindstone in a lathe.

simultaneously. Grindstone lathes are operated by steam, electricity, gasoline, or natural-gas engines, the choice of power depending upon relative costs and availability. Most lathes are provided with suction pipes in the pits to carry away the dust and thus reduce the danger of its injurious effects upon workmen.

Smaller stones which are not circular are mounted in lathes and marked at each side for their proper circumference by holding pointed tools against them. The grooves are not cut deeply into the rock as this would involve the danger of masses of rock flying from the stones, impelled by centrifugal force. While the stones are at rest the outer masses are broken off with hammers and thereafter the stones are turned to finished form in the usual way.

Cutting and Carving.—A certain amount of hand cutting is necessary, especially in plants where building stone is produced. It involves

rough work, such as the cutting of rock-face ashlar from irregular waste blocks, and also the finer carving required for decorative effects. Sandstones are so variable in character that both methods and tools differ widely in various localities. For example, a light and springy tool "plucks" less than a heavy tool in the fine-grained sandstones of McDermott, Ohio. The best methods of cutting and the most efficient tools to use can be determined only by experience.

Handling of Material.—Stone is a heavy material, and speed in mill work demands the most efficient types of crane service. Derricks are sometimes employed, but the overhead traveling crane is handled more quickly and easily and has a wider range. Pneumatic cranes give very efficient service for handling the smaller pieces, such as curbstones. In some Ohio curbing mills a pneumatic crane of 2,000-pound capacity serves each planer, and other cranes are employed for yard service.

THE BLUESTONE INDUSTRY

Definition of Bluestone.—Bluestone is a commercial name for a variety of sandstone having properties sufficiently characteristic and distinctive to justify its recognition as a separate rock type. It may be defined briefly as an indurated arkose sandstone, most of which splits easily into thin, smooth slabs. The term was first applied to certain blue sandstones quarried in Ulster County, N. Y. With the development of the industry it was found that stone of similar character was abundant in various other localities in New York and in Pennsylvania. Although they differ considerably in composition, size of grain, and color, all are dense, compact, hard, and usually dark, and, particularly in the upper beds, split into thin and uniform slabs. The term "bluestone" therefore is applied to all varieties, irrespective of color. Blue, gray, red, pink, and greenish colors have been observed.

Composition of Bluestone.—After making a microscopic study of bluestone from Ulster County, N. Y., Berkey[11] states that the rock consists of feldspars, quartz, sericite, chlorite, calcite, clay, and a little pyrite and organic matter. Hornblende and biotite probably were present in the rock originally but have altered entirely to the more stable sericite and chlorite. The grains are angular and are held together with a strong, siliceous cement. Although certain variations in composition and texture may occur in bluestone from different localities, in general they are all of this type.

Structural Features. *Joints.*—Joints usually are in two vertical systems, nearly at right angles to each other and spaced 5 to 70 feet apart. Generally the systems are north-south and east-west; the former are termed "heads" and the latter "sides." Usually joints are

[11] Berkey, C. P., Quality of Bluestone in the Vicinity of Ashoken Dam. Columbia Sch. Mines Quart., vol. 29, 1907–1908, pp. 154–156.

straight, though sometimes they are curved and irregular. Moderately spaced straight joints are of great assistance in quarrying.

Beds and Reeds.—Most bluestone beds lie horizontal or nearly horizontal. Open bedding planes are a few inches to several feet apart, or in the massive rock may be at 25- to 35-foot intervals. Inter-bedded shales are common, such rock being termed "pencil" by quarrymen.

The chief characteristic of bluestone is its weak cohesion in certain well-defined planes, resulting in a strong tendency to split in thin sheets that parallel the bedding. In the upper beds the partings usually are developed to such an extent that the rock splits with great ease into large, thin slabs. At greater depths the partings are less pronounced, though in most beds the rock may be split easily along certain streaks termed "reeds," which have already been defined. The presence of reeds has made bluestone a valuable rock for the production of flagging.

In some deposits or in certain parts of deposits reeds are lacking. Cross-bedding may be present, or the rock may be massive—a "liver rock." In some quarries such beds are avoided because flagging can not be made from them. However, they are the strongest and most durable and therefore the most valuable for structural purposes.

Run.—In bluestone there is usually one vertical plane in which splitting is comparatively easy. This is known as the "run" of the rock or the "free way," and the vertical plane at right angles to it is termed the "hard way." Fortunately in most deposits the run parallels one of the major jointing systems, thus permitting easy separation of right-angled blocks.

Strength and Durability.—Good-quality bluestone is very strong. Berkey[12] states that the great strength of the rock is due to the facts that alteration of the ferromagnesian and aluminous minerals has freed considerable secondary quartz, which has attached itself to the original quartz grains, making them more angular and developing an interlocking texture, and that the secondary fibrous minerals have promoted further interlocking of the grains.

Bluestone is probably the most durable of any quarried stone except quartzite. The coarse-grained varieties are somewhat more resistant to weathering than those of finer grain. The presence of clay in a bluestone renders it less durable. In natural outcrops of bluestone along steep hillsides the more durable beds can be recognized easily by their steep, almost clifflike contour, whereas the softer, more easily weathered beds outcrop as more gradual slopes. Thus, if the ledge consists of alternate hard and soft beds, the face of the hill will present a series of terraces.

Uses.—Bluestone has been used very widely for sidewalks and flagging. It is well-suited for these purposes, as it resists wear and does not become

[12] Berkey, C. P., Work cited, p. 157.

slippery. Bluestone with the reeds spaced more widely than in sidewalk stone is used for curbing, steps, sills, caps, water tables, and coping. Heavy mill blocks are sawed into forms suitable for the various purposes mentioned above, or into building blocks. The rock is used to some extent for floor tile. Various colors may be combined to make attractive floor patterns or borders. The more massive varieties of bluestone are suitable for heavy masonry.

Commercial Types.—The primary product of the quarry is marketed in three forms—flagging, "edge stone," and "rock" or mill blocks. Flagging is stone from beds that split with remarkable ease into thin, uniform sheets. Commonly the slabs are 10 by 12 feet and only 2 inches thick. What is termed "edge stone" splits out in thicker beds and is dressed for curbing, sills, caps, and coping or other similar uses. "Rock" or mill blocks are taken from the more massive beds that are not reedy and are therefore well-suited for structural purposes. Mill blocks are more valuable per cubic foot than the other forms quarried.

Quarry Methods. *Types of Quarries.*—Bluestone quarrying differs from most other types because there are few large operations and many small ones. Numerous small openings quarried by one to eight men are operated in summer, some being worked only at brief intervals in connection with farming or other occupations. The product is hauled by teams or automobile trucks and sold to stone dealers. Although the quarries are small, total production amounts to considerable quantities; New York and Pennsylvania, the chief producing States, normally sell annually an amount valued at about $1,000,000 at the quarry.

Quarry Equipment.—In many small quarries the equipment is limited to the necessary tools and appliances, such as crowbars, shovels, hammers, points, drills, wedges, picks, plugs, and feathers. In numerous quarries no derricks are provided, the rock being handled by crowbars. Hand-power or horsepower derricks are common, though steam or gasoline engines are employed in some places. Some derricks are provided with gears giving two speeds, a rapid speed for light loads and a slow speed for heavy loads. Some of the larger quarries have compressed-air plants for operating drills. For drainage purposes steam or gasoline pumps or pulsometers are operated in a few places. In others, siphons are employed, and in many quarries conditions favor automatic drainage. A blacksmith shop for sharpening and shaping tools is a necessity at every quarry.

Separation of Larger Masses.—When vertical seams occur in two systems at right angles to each other and 10 to 30 feet apart they are of great assistance in quarrying, and the quarryman endeavors to work to these seams wherever possible. Where seams are far apart artificial cross breaks must be made, a process known locally as "snubbing," which usually is accomplished by drilling holes about 6 feet apart and blasting by the Knox method, as described on a previous page. The

masses thus separated may be 15 or 20 feet in lateral dimensions and 1 to 3 or 4 feet thick depending upon the spacing of the open-bed seams. Another method less commonly used is to drill a row of holes 1 or 1½ inches apart and to broach out the cores between them, making a continuous cut.

Cross Breaks.—For smaller cross breaks, particularly those in thin-bedded rock, the wedging method is employed. In drilling wedge holes a "starter" and a "follower" are sometimes used. The starter drill is commonly 1⅛ inches in diameter and drills only the upper 1½ inches of the holes. Then the follower, a drill of ⅞ inch diameter, finishes the holes. In the process of wedging in such holes the pressure of the plugs and feathers comes at a point some distance below the surface of the rock, whereas if the holes are of the same size throughout their full depth the pressure is inclined to be excessive near the surface, causing the rock to shell off. A row of pick holes along the line helps to make a straight break. Wedge holes may be spaced considerably farther apart when splitting parallels a pronounced run than when a break is made parallel with the hard way.

For separation of large masses blasting sometimes gives better results than wedging. A charge of black blasting powder fired in a single reamed hole may make a straight break 12 to 18 feet long and 3 to 4 feet deep. In many quarries it is customary to blast the rock parallel with the run and to wedge it the hard way.

Splitting Beds.—In rocks in which the reeds are pronounced, beds are easily split by wedging, but more massive rock, with greater difficulty. A typical method is to cut notches about ½ inch deep and 3 inches apart across both ends and along one side of the block. A fracture is started by driving points into the holes successively first at one end of the block and then at the other end. When a fracture is formed some distance from each end thin wedges are driven into it at both ends and on the edge. The block is then turned down and started on the opposite edge, and the fracture is completed by wedging. When the process is thus carefully conducted it gives a uniform fracture. A bull wedge sometimes is used in splitting curbstones.

Trimming.—There is usually need of trimming edges, especially where such products as curbstones, steps, and coping are made. Where curved corner curbstones are made much trimming is necessary. With careful handling two corner curbs may be broken from a single block by making a curved break. The amount of trimming required is influenced by cross bedding, which may result in oblique splitting of beds. If a slab for curbstones is thicker at one edge than the other, it is "pitched off" with a hand tool and hammer, a process that wastes rock and requires much time and labor. When trimming is done in the quarries hand tools and hammers generally are employed.

Marketing Bluestone.—Operators of the many small bluestone quarries sell their products to stone dealers, or dealers may operate the quarries themselves. They have yards termed "docks," situated on navigable water or railway lines, where stone from the quarries is unloaded and shipped by rail or water to its destination. The docks almost invariably are equipped with derricks. Transportation is usually by wagons and trucks, as very few quarries have railway sidings. The cost of transportation is borne by the quarryman and ranges from 8 to 50 per cent of the value of the stone, depending on the haulage distance and the condition of roads. Structural stone is sold to building contractors, and curbing and flagging to street-construction contractors, highway boards, or municipalities.

WASTE IN SANDSTONE QUARRYING AND MANUFACTURE

Cause of Waste.—Even in sandstone deposits of the highest quality much rock is either unsuitable for use or is wasted in quarrying and manufacture. Much of the waste may be due to imperfections in the rock, over which man has no control. Joints may be irregular or closely spaced, or they may intersect at sharp angles. Bed seams may be close together or wavy and uneven, or the rock may be cross-bedded, with intersecting bed seams. The texture may be uneven, and the degree of cementation may lack uniformity. Iron compounds may cause stains, and the presence of clay may increase the absorption. Such defects in composition and structure may bring about the rejection of many blocks of stone.

Much serviceable rock is wasted in quarrying and milling. Excessive blasting with unnecessarily heavy charges, the "stunning" of channeling machines, and improper wedging are common causes of excessive waste. Even in the best-conducted quarries and mills part of the good stone must be cut and trimmed away to fashion blocks and slabs to their required shapes and dimensions. Therefore, the volume of finished products may be less than one-half of the gross quarry output.

Waste Utilization.—Sandstone is chemically inert, and its waste products therefore have much more limited application than waste limestone or marble. However, the economical quarryman seeks to cultivate certain fields of utilization to win some profitable return from at least part of his waste material. Heavy, irregular blocks of sandstone unsuitable for other use may be used for shore protection along rivers, for spillways at dams, or for the construction of harbor breakwaters. Irregular small fragments which have one good face are used to some extent as rubble, though rubblestone has been displaced by concrete quite generally during recent years. Waste blocks may also be trimmed to suitable sizes and shapes for regular course or broken ashlar walls. Waste sandstone may be crushed for concrete aggregate. As a rule, sandstone is not

suitable for road surfaces, although some argillaceous sandstones contain enough binding material to render them satisfactory. Some quartzites are used for road surfaces where traffic is heavy. Sandstones are more suitable for road bases, as they provide good drainage and cushion, and a market for waste is found in this field.

Sand is an important by-product at many sandstone plants, especially where the more friable types are worked. The sand may be used for sand-lime brick manufacture, for mortar, for furnace floors, or as engine sand. The utilization of pulverized sandstone as asphalt filler is receiving some attention.

Prevention of Waste.—In view of the limited number of uses for which waste sandstone may be employed, quarry operators endeavor to keep the proportion of waste at a minimum by quarrying in accordance with joint systems and other rock structures, by exercising great care in blasting, by employing skill and good judgment in wedging, and by careful selection of rock that it may be suitable for its intended use. Waste may be reduced by skillful milling. Blocks containing streaks or spots may be cut in such manner that the blemishes do not appear on exposed surfaces. There is an advantage in operating a mill in connection with a quarry, for the quarryman understands his rock and can therefore cut it to much better advantage than a millman unacquainted with its peculiarities.

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CHAPTER VIII

GRANITE

GENERAL CHARACTER

As pointed out in the discussion of rock classification, granite is of igneous origin, coming up from unknown depths; thus, except in rare instances, it may be relied upon to extend downward far beyond the possibility of economical quarrying. Granites and related rocks are the hardest of all ordinarily used for structural purposes and the most difficult and expensive to quarry and shape into finished forms. The many troublesome problems that confront the granite quarryman have stimulated his inventive genius to devise new and better ways of winning this important structural material from the earth and fashioning it into useful and attractive products. The technology of granite is therefore, of unusual interest.

MINERAL COMPOSITION

Chief Minerals.—The essential constituents of granite are feldspars, quartz, and either mica or hornblende; and their proportions vary greatly. According to Merrill,[13] one European granite contains 52 per cent feldspars, 44 per cent quartz, and 4 per cent mica; another contains 35 per cent feldspars, 59 per cent quartz, and 6 per cent mica. Granites as high in quartz as these are very difficult to work, but few quarried in the United States have as large a proportion as these foreign granites. The red granite of St. Cloud, Minn., contains 70 to 80 per cent feldspars, 15 to 20 per cent quartz, and 5 to 10 per cent combined mica and hornblende. Dale[14] found that a Hardwick (Vt.) granite contains about 62 per cent feldspars, 22 per cent quartz, and 16 per cent biotite mica. He also states[15] that dark Barre granite contains about 65 per cent feldspars, 27 per cent quartz, and 8 per cent mica.

A simple method of determining the proportions of the chief constituent minerals is described by Dale.[16] A network of lines intersecting at right angles is traced on the polished surface of granite and spaced at such intervals that no two parallel lines will traverse the same mineral

[13] Merrill, G. P., Stones for Building and Decoration. 3d ed., John Wiley & Sons, Inc., New York, 1910, p. 46.

[14] Dale, T. Nelson, The Commercial Granites of New England. U. S. Geol. Survey Bull. 738, 1923, p. 110.

[15] Work cited, p. 124.

[16] Work cited, p. 100.

grain. The total length of the lines is measured, the diameters of all the particles of each mineral variety are added separately, and their proportion to the total length of the lines is calculated.

Feldspars are the most conspicuous and ordinarily the most abundant minerals in granites. Several kinds usually are present. The potash feldspars (microcline and orthoclase) are the most prevalent and are generally accompanied by small percentages of one or more members of the lime-soda group (the plagioclases). Feldspars may be white, gray, opalescent, reddish, brown, or green, and the prevailing color determines to a large extent that of the rock. Quartz grains may be recognized readily by their glassy luster, absence of cleavage, and uneven fracture surface. Quartz is commonly clear and transparent but may be milky, bluish, yellow (citrine), opalescent, purple, or smoky. Next to the feldspars and quartz, black mica (biotite) is the mineral most abundant in a majority of granites; dark green or black hornblende may be nearly as abundant; and muscovite frequently occurs. When large percentages of biotite or hornblende are present the rock may be nearly black.

Accessory Minerals.—Accessory minerals are those that may or may not be present in a rock. When present they are usually in subordinate amounts, and some may be detected only with a microscope. Garnet, zircon, epidote, titanite, magnetite, hematite, limonite, ilmenite, pyrite, apatite, augite, and rutile are the more important accessory minerals of granite, and minute quantities of many others may occur.

CHEMICAL COMPOSITION

The chemical composition of granite has little economic significance. Many prospective granite-quarry operators wish to have samples of their rock analyzed to determine its quality and probable value, failing to realize that any one element or compound may form constituent parts of several different minerals, some of which may be desirable and some undesirable. For example, an analysis may show a certain amount of iron, but without a very complete analysis and careful calculation the amount of iron present as a constituent of a stable biotite or hornblende or of an unstable and detrimental pyrite or garnet can not be determined. A chemical analysis, however, may indicate the general composition; thus a high silica content would indicate a high percentage of free quartz. Analysis of a granite is therefore much less important than determination of its mineralogical composition.

PHYSICAL PROPERTIES

The adaptability of a granite for structural or ornamental use is governed mainly by its physical properties, the character of its constituent minerals, and their grouping.

Texture.—The texture of granite signifies the size and arrangement of mineral grains. Uniform grain size usually is demanded in commercial granites for building or ornamental uses. Lack of such uniformity condemns thousands of deposits throughout the world for practical use. Grain size varies greatly in different granites. They accordingly are classed as fine-, medium-, and coarse-grained. Medium-grained granites are those in which the feldspars average about one-fourth inch across.

Uniform distribution of the minerals is as important as uniform grain size. Light and dark minerals should be distributed evenly throughout the rock mass, for this gives uniform color and texture. Many commercial deposits display remarkable homogeneity; the rock may not vary in color or texture for many feet, either vertically or horizontally. A number of granite enterprises owe their success to such consistent qualities.

Color.—The color of a granite is governed largely by that of the feldspar, usually the most abundant mineral. However, it may be modified to some extent by the quartz, hornblende, or mica, if considerable amounts are present. White, light gray, dark gray, pink, red, and olive-green commercial granites are common. Uniform color distribution is a desirable feature.

Hardness.—The hardness of a granite is determined by that of its constituent minerals. As feldspar and hornblende have a hardness of about 6, and quartz of 7, all granites must be exceedingly hard. Those having abundant quartz are the hardest. Some are quite brittle and shatter readily, while others have interlocking grains that make them very tough and consequently difficult to separate by blasting or wedging.

Porosity.—Although freshly quarried granite appears very dense and impervious to moisture, investigations by Merrill, Watson, Buckley, Parks, and others show that the pore space of average granites is 0.10 to 0.50 per cent. These microscopic pores are both within and between the mineral particles. Dale[17] states that an average granite contains 0.8 per cent water and can absorb about 0.2 per cent more; that is, 1 cubic yard of granite weighing about 2 tons contains about 3½ gallons of water and if immersed can absorb nearly 1 gallon more.

Although the total pore space is very small it may have interesting effects. Pores of subcapillary size do not give up their water content readily and damage from frost action may result. As will be shown later, the fluidal cavities in quartz probably bear definite relation to the rift.

VARIETIES

Granites generally are named from the most prominent ferro-magnesian mineral present; thus, they may be called "biotite granites," "hornblende granites," or, more rarely, "augite granites." If two such

[17] Work cited, p. 12.

minerals are prominent a compound word may be used, as "hornblende-biotite granite." The name "binary granite" is sometimes given to one consisting only of quartz and feldspars. Sometimes granites are named from an unusually prominent accessory mineral, as "epidote granite" or "tourmaline granite." Classification by color provides for red, gray, white, or other groups.

Granites are also classed according to texture. They may, for example, be designated "fine-grained" or "coarse-grained." "Porphyritic granite" consists of relatively coarse grains in a fine-grained groundmass. The term "aplite" is usually applied to a fine-grained, light-colored granite that occurs in dikes. A rock may have the mineral constituents of a granite but show a banded arrangement of light and dark minerals, owing to folding while the rock was plastic or semimolten. Such metamorphic rocks (gneisses) are classed commercially with the granites and may be designated "gneissic granites."

RELATED ROCKS

Granite is only one of many igneous rocks, but it occupies so prominent a place in any discussion of dimension stone that the other less important types are included with it. When igneous rocks are considered for building and similar purposes granite predominates for two reasons. First, there are few other igneous rocks of composition, texture, or color suitable for structural or ornamental uses. Second, most igneous rock types so employed are classed commercially as granites, even though some are far removed petrographically.

Certain related varieties are logically classed with granites, as they are so similar as to be distinguishable only by very careful examination, sometimes only by the use of a microscope. The more prominent of these closely related types are syenite, diorite, quartz diorite, and quartz monzonite.

Other rocks classed commercially as granites differ sharply from them. The most important of the distantly related types are the so-called "black granites," which may be gabbros, diabases, or dark diorites. They are similar to true granites in structure and texture but consist essentially of plagioclase feldspar and augite, with little or no quartz. Some are quite ornamental, will take a high polish, and are used in the same way as granites. Rhyolites and volcanic tuff, uses of which are limited, also are distantly related to granites.

STRUCTURAL FEATURES

Certain structural features affect both the quality and workability of granite. Joints, sheet structure, rift, grain, dikes, knots, and hair lines are the most important.

Joints.—Joints, or seams, are natural fractures that traverse the granite mass, usually in a nearly vertical direction. Dynamic geologists

generally agree that they are caused by compressive or torsional strain, which has been resolved into two components, each at an angle of about 45° with the direction of strain. This theory has some confirmation in the fact that joints occur quite generally in two main systems, called "major" systems, which intersect at about 90°; less prominent systems are termed "secondary." Joints may have resulted from a constant force exerted in one direction over a wide area, for the systems tend to run in the same compass directions in many quarries throughout an extended deposit. Thus, in the St. Cloud (Minn.) region, where the

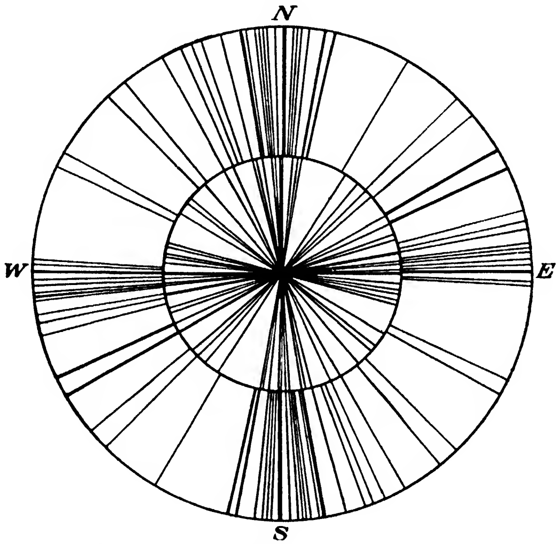

FIG. 21.—Strike of major and secondary joints in granite deposits near St. Cloud, Minn.

writer some years ago took numerous compass readings, most of the major joints strike either approximately north and south or east and west, as shown diagrammatically in figure 21.

Major systems are common in granite deposits, but many intermediate and irregular joints may occur, and in some deposits no systematic arrangement may be evident. Obviously an arrangement in two parallel systems meeting at right angles, with few intermediate or irregular joints, is the most favorable for quarrying, as it facilitates removal of blocks and maintains a low percentage of waste.

The spacing of joints is extremely variable. If they are only a few inches apart the rock is useless as dimension stone, except possibly for small rubble. Straight major joints 10 to 30 feet apart usually are regarded as advantageous in quarrying. If only 3 or 4 feet apart, blocks of sufficient size may be obtainable, but the rock may be stained by weathering agencies acting from the joint walls. Such staining detracts from its quality for memorial uses but may be an asset for certain archi-

tectural effects now in demand. In some localities, such as the Lithonia district of Georgia and the Mount Airy region of North Carolina, the rock may be sound and massive over wide areas without any joints.

Sheeting Planes.—Sheeting planes are approximately horizontal partings that separate a granite mass into sheets or layers. They generally parallel the rock surface and are consistently closer together near the surface than at depth. In some granites they are very prominent and closely spaced. On Crotch Island, Me., they are only 2 to 4 feet apart near the surface and present, although more widely spaced, at a depth of at least 140 feet. Widely separated sheeting planes occur at a depth of 250 feet at Quincy, Mass. In the St. Cloud district, Minnesota, they are few and widely separated. As a rule, they are more closely spaced than joints in New England, while the reverse is true in Minnesota. On this account quarrymen who have worked both in New England and in the St. Cloud district describe the rock of the latter region as "standing on end." Just as the granites of Lithonia, Ga., and Mount Airy, N. C., are crossed by few joints, so are they without sheet structure. In such deposits artificial sheets must be forced in the process of quarrying.

The origin of sheeting planes is obscure. Dale[18] discusses in some detail all the theories advanced, concluding that compressive strain was probably the main factor in producing them, though expansion under solar heat may have been a contributory cause in the surface layers. The arched structure commonly found in sheeting planes may account for the conspicuous domelike form that characterizes many granite deposits.

Rift and Grain.—Many granites split in some directions with greater ease than in others. The direction of easiest splitting or the fracture system that makes splitting possible is called the "rift." A second less strongly marked fracture system may stand at right angles to the rift. It is generally called the "grain," but in Minnesota it is called the "run." The direction at right angles to both rift and grain is called the "hard way" or "head grain."

In Minnesota the rift is nearly always horizontal, and the grain in some vertical plane. In many Vermont and Maine quarries conditions are reversed, the grain usually being horizontal and the rift vertical. In New Hampshire conditions more nearly resemble those in Minnesota. There are many variations, but one direction of comparatively easy splitting is almost invariably horizontal and the other at right angles to it. The direction of grain may be constant over a wide area. Thus, throughout central Minnesota the grain like the major joints is predominantly north and south, except in one small area where it is east and west.

[18] Work cited, pp. 26–36.

The origin of rift and grain, like that of sheeting planes, is obscure. They are apparently independent of sheets and of flow structure. According to Dale they are caused principally by orientation of the minerals —that is, by the arrangement of the minerals in lines or planes or with parallelism in their cleavage directions. They may also be caused by the arrangement of fluidal cavities in parallel planes in the quartz grains; by incipient jointing caused by strain; or by microscopic faults or fractures. That rift and grain in the granites of central Minnesota originated in orientation of minerals is indicated rather definitely by two facts: First, the rift surface is smoother than other surfaces. A skilled paving-block cutter can detect the rift blindfolded by the feel of the surface. This condition would indicate predominance of feldspar cleavage faces parallel to the rift. Second, some quarrymen have stated that they recognize the rift by "the direction in which the grains point." They appear to base their observations rather on the dark than on the light minerals.

Some granites display no evidence of rift or grain. Even in rocks in which they are most fully developed rift and grain are obscure properties that may be recognized only by a skilled stonecutter. Nevertheless, they are of the utmost importance in quarrying, as they make splitting easy and give comparatively smooth, uniform surfaces. Paving-block cutters are exceptionally skilled in recognizing rift. It may be safely said that the granite paving-block industry could not exist were it not for rift and grain in the rock.

Dikes.—Dikes are defined as fissures filled by mineral matter injected in a plastic to fluid condition. Dike material is of two main types—acidic or basic; that is, it may be siliceous, like granite, or may contain a large percentage of ferromagnesian minerals, thus having the composition of a basalt or diabase. Dikes in granite deposits may range in width from a fraction of an inch to several feet and occasionally to 50 or even 150 feet.

Acidic Dikes.—Some dikes consist of granite which differ radically from that into which it is injected. In Minnesota, red granite dikes commonly traverse gray granites. The well-known granites of Westerly, R. I., are quarried in a formation that has been interpreted as a great dike 50 to 150 feet thick. The occurrence of commercial granite in dike form is quite exceptional.

Aplite dikes—fine-grained, light-colored granite—are very common. They are usually quite narrow, and their fine-grained texture probably is due to comparatively rapid cooling caused by contact with the previously solidified rock masses on either side.

Pegmatite, according to Hess,[19] is a general name for rocks with coarsely and unevenly crystallized segregated minerals occurring as

[19] Hess, Frank L., Pegmatites. Econ. Geol., vol. 28, no. 5, 1933, pp. 447–462.

dikes, veins, or metamorphic masses. During their formation the constituents of ordinary granite were supplemented by water vapor and numerous volatile elements, such as fluorine, chlorine, boron, phosphorus, and sulphur. A slow process of crystallization and mineral replacement caused large crystals of feldspar, quartz, and mica to form, and associated with them in many places was a series of characteristic pegmatite minerals, such as tourmaline, scheelite, garnet, cassiterite, apatite, and beryl.

Pegmatites supply practically all the feldspar and sheet mica of commerce but have little value as sources of structural or ornamental stone.

Basic Dikes.—The more common types of basic dikes are those termed "diabase" or "trap" dikes. They are dark green, dark gray, or black, are very hard and dense, and are common in many granite regions. More than 360 have been counted in the Rockport quarries, Cape Ann, Mass.

Effect of Dikes on Granite.—Granite traversed by dikes of any kind rarely is utilized as dimension stone. Basic dikes, particularly, stand out as dark, conspicuous bands that mar the appearance of the stone. They are unwelcome in quarries because of the time and labor wasted in removing them and of the granite they render valueless commercially. It has also been observed that rock near dikes tends to be unsound. Such a condition is to be expected, because the shattering which formed the open fractures into which the dike material was injected may have developed fine cracks or incipient seams in the near-by rock.

In some deposits, however, granite close to dikes, though not actually cut by them, may be of good quality. The heat of the dike material may have developed minute cracks in the quartz and feldspar of the adjoining granite, but this contact effect may not extend beyond a depth of 1 or 2 inches.

Knots.—The term "knot" is applied to a circular, oblong, or irregular mass that commonly occurs in a granite otherwise of uniform texture. Knots are usually dark and are regarded as serious blemishes, particularly on polished surfaces, where they stand out like blots on a sheet of paper. As they in no wise affect strength or durability, stone containing them may be used for curbing, paving, or other purposes where color means little. Knots are of two kinds—segregations and inclusions.

The more common types are segregations—groupings of dark minerals in spots during cooling and solidification. Segregations consist of the same minerals as the parent rock; but the dark minerals, hornblende and biotite, are more abundant than the light quartz and feldspar. Both the origin and distribution of segregations are difficult to explain. No conclusions have been reached regarding their occurrence, and the probability of their presence or absence in any locality is a matter of mere speculation.

Knots designated as "inclusions" are masses of foreign material caught up by a semiliquid magma and held within it until the whole has solidified. Such knots are somewhat angular and comprise material different from the rock in which they are inclosed. As inclusions consist of foreign materials they are most apt to occur near the borders of granite masses—that is, in the zones nearest contact of the granite with other rocks.

Methods of Distinguishing Knots.—As noted previously, some rules can be laid down for the occurrence of inclusions, but none have been established for segregations. At times, therefore, it is rather important to interpret the origin of knots and classify them correctly. A specific example best illustrates the method of interpretation. In a certain granite two types of knots occur. Microscopic examination in thin section reveals that one consists of orthoclase, plagioclase, quartz, and biotite, the same minerals that occur in the surrounding rock, though the proportion is different, biotite being in excess. These minerals have the same peculiarities as corresponding minerals in the main rock mass; for example, the biotite contains inclusions of apatite and zircon, a condition characteristic of this granite. Such knots are undoubtedly segregations. The other type of knot is quartz and biotite, with no feldspar. The mica flakes show parallel orientation and have no inclusions of apatite or zircon. Therefore, the minerals have different characteristics from corresponding minerals in the surrounding rock, and their character and arrangement suggest the probability that the knot is an inclusion of biotite schist. The shape of knots is also indicative of their origin, angular knots being inclusions and ellipsoidal or spherical knots more probably segregations.

Hair Lines.—The term "hair line" is applied in some regions, particularly in Minnesota, to all fine lines of discoloration in granite. These lines are practically unrecognizable on rough or tooled granite and therefore are objectionable only on polished surfaces, where they stand out quite prominently and detract greatly from appearance. Some black hair lines appearing in granite close to trap dikes are really minute dikes; others are very small veins filled with dark or smoky quartz. Green hair lines, consisting of epidote veinlets, are common. If they follow joint systems they are unimportant, but if they wander irregularly they may mar the stone. Quarrymen examine rock very carefully for hair lines before selecting it for monumental purposes. They can be observed best if water is thrown over the surface.

USES

Dimension granite is used for five principal products. These are, in order of their production value: Monumental stone, building stone, paving blocks, curbing, and rubble. Only stone of the highest quality is

used for monuments, because much of it is polished and polishing emphasizes all defects. Increasing quantities of polished granite are being used also for structural purposes, not only because it is attractive, but because it is easily cleaned and is not soiled so quickly as unpolished granite; therefore, highly ornamental stones, as well as the more ordinary types, are used for building. For paving blocks and curbing appearance is less important.

The following table, compiled by the United States Bureau of Mines, indicates the amount and value of granite sold for various uses.

GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1936 AND 1937, BY USES

Use	1936		1937	
	Quantity	Value	Quantity	Value
Building stone (rough and dressed), cubic feet	2,619,700	$ 2,629,090	3,322,830	$ 3,068,155
Approximate equivalent in short tons..	217,070	....	274,930	
Monumental stone, cubic feet	2,478,380	6,440,878	2,657,630	6,628,447
Approximate equivalent in short tons	203,610	....	218,400	
Paving, number of blocks	6,826,333	702,828	7,866,994	780,611
Approximate equivalent in short tons	70,500	....	73,770	
Curbing, linear feet	1,189,680	1,206,113	881,310	825,148
Approximate equivalent in short tons	98,220	....	72,790	
Rubble, short tons	77,450	117,835	111,440	149,958
Total value ...	.....	$11,096,744	......	$11,452,319

The corresponding total for 1929 was $25,369,396 and for 1932, $11,743,408.

DISTRIBUTION OF DEPOSITS

Granites are quarried in many parts of the United States, but the principal deposits may be grouped in four chief areas, as follows: (1) The Appalachian district of eastern United States, from Maine to Georgia; (2) the Middle Western States, particularly Minnesota and Wisconsin; (3) the Rocky Mountain States, where deposits have not been developed extensively; and (4) the Pacific Coast States, particularly California. The general distribution of granites in the United States is shown in figure 22. The leading producing centers for monumental granite are Barre, Vt., Quincy, Mass., and St. Cloud, Minn. In order of production value of monumental stone in 1928 the 10 leading States were Vermont, Minnesota, Wisconsin, Massachusetts, California, Georgia, Rhode Island, North Carolina, New Hampshire, and Maine, which produced about 86 per cent of the total. The 10 leading States in order of production value of building stone for the same year were Massachusetts, Minnesota,

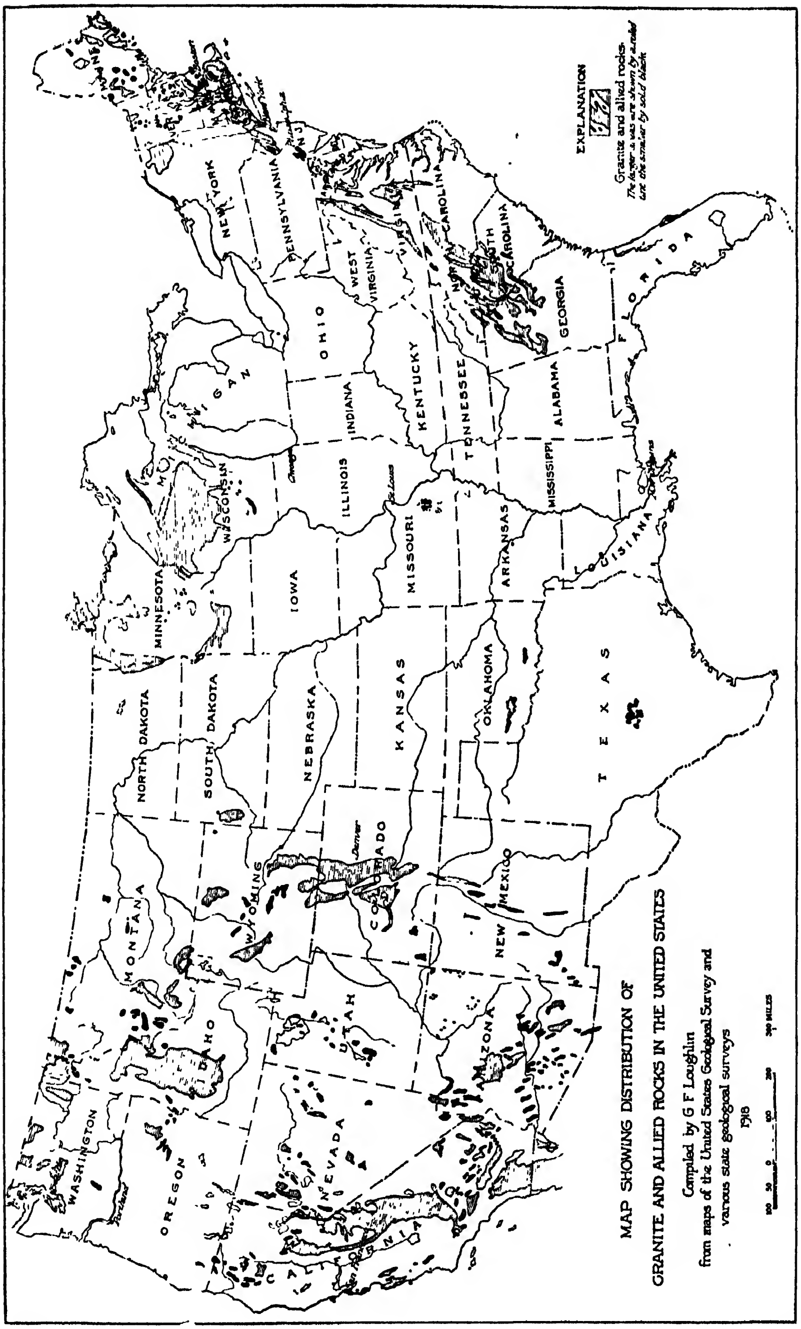

FIG. 22.—Map showing general distribution of granite areas in the United States. (*Courtesy of National Building Granite Quarries Association, and Federal Board of Vocational Education.*)

North Carolina, New York, New Hampshire, Maine, Georgia, Maryland, Pennsylvania, and Vermont. The totals and relative standing of the States vary from year to year. Figures may be obtained from the U. S. Bureau of Mines, which annually publishes complete statistics by States and uses.

INDUSTRY BY STATES

About 96 per cent of the production value of granite dimension stone is confined to 16 States, which may be arranged in two groups, those of major importance as producers and those less important. The first group, comprising the following States, listed in order of production in 1928, furnished about 81 per cent of the total quantity for that year: Vermont, Massachusetts, Minnesota, North Carolina, Maine, Georgia, Wisconsin, and New Hampshire. The second group, accounting for about 15 per cent of the total production, included New York, California, Maryland, Rhode Island, Connecticut, Pennsylvania, South Dakota, and Texas.

The order of arrangement of the States and much of the statistical data given in the following pages are based on 1928 production because a fairly complete analysis of the 1928 figures has been published.[20]

PRINCIPAL PRODUCING STATES

Vermont.—Vermont, with an output valued in 1928 at $4,227, 525, or 17.1 per cent of the total for block granite in the United States, is the largest producer in the country. It specializes in monumental stone, a material that accounts for about 96 per cent of the total value of granite produced in the State. About 36 per cent of the monumental stone of the United States was produced in this State in 1928. The total output in 1929 was valued at $4,113,886, in 1930 it was $3,348,938, in 1936, $2,238,724, and in 1937, $2,511,986.

In this and in most of the States the granites are described briefly by counties in alphabetical order.

Caledonia County.—The Newark rock is a coarse-grained, light pinkish gray biotite granite marketed as "Newark pink." The Kirby Mountain granite, which is bluish gray and medium- to fine-grained, has been worked to a limited extent. The Hardwick granites, which are fine to medium, even-grained and bluish gray, are well-known to the monument trade as "Hardwick" and "Dark Blue Hardwick." Typical "Ryegate" granite, also known as "Vermont gray," is a medium-grained, light gray stone suitable for monuments or building. Stone of a decided blue-gray, "Vermont blue," is quarried at Groton.

[20] Bowles, Oliver, and Hatmaker, Paul, Trends in the Production and Uses of Granite as Dimension Stone. Rept. of Investigations 3065, Bur. of Mines, 1931, 21 pp.

Orleans County.—The rock at Derby is a fine-grained, light bluish gray biotite-muscovite granite, sold chiefly for monuments and monument bases under the trade name "Derby Gray." Sheeting planes are 3 to 18 feet apart, and one set of vertical joints provides a heading at the north wall of the quarry. • Quarrying was begun about 1880.

Washington County.—The district surrounding Barre and Graniteville, Washington County and Williamstown, Orange County is the most important monumental granite-producing center in the United States. The granite occurs in two prominent domes, Cobble Hill and Millstone Hill; the latter supplies most of the commercial stone. The two hills are regarded as parts of a single mass appearing at or near the surface in an area 4 miles long and 2½ miles wide. The rock is a fine- to medium-grained gray to white biotite granite; the various shades are designated as "white Barre," "light Barre," "medium Barre," "dark Barre," and "very dark Barre." The darker varieties are most in favor for monument dies and the lighter for buildings, mausoleums, and monument bases. An average sample of dark Barre granite consists of about 65 per cent feldspars, 27 per cent quartz, and 8 per cent mica.

Sheeting planes 6 inches to 30 feet apart are present in some quarries; in others they are spaced more widely or are absent. Masses 40 to 80 feet thick without sheeting planes have been encountered. This incomplete development of sheet structure makes quarrying difficult. Joints are irregular, following at least five different compass directions. The spacing also is quite variable, ranging in most quarries from 1 to 50 feet and in others from 100 to 200 feet. Black knots rarely occur. Its remarkably uniform texture is one of the chief assets of Barre granite. The rift ranges from 85° to vertical and varies somewhat in direction, on Millstone Hill from N.30°E. to N.60°E., and on Cobble Hill from N.50°E. to N.75°E. Almost invariably the grain is horizontal. Pegmatite, aplite, and basic dikes occur but are not numerous.

For many years a dozen or more large companies operated quarries in this district. Recent consolidations have reduced the number, though the extent of operations has not been curtailed.

Monumental stone is the chief product. The industry consists of two distinct branches—quarrying and manufacturing. Some quarry companies also manufacture; but most of them produce rough blocks only, which they furnish to neighboring manufacturing plants and ship to all parts of the country. Figures compiled by the Barre Granite Manufacturers' Association show that the quarries of the district produced 1,549,443 cubic feet of rough stock in 1928. Of this amount, 1,239,554 cubic feet were manufactured in the district and 309,889 cubic feet shipped as rough blocks. More than 100 plants for the manufacture of granite products are situated in and about Barre, Montpelier, and neighboring towns.

Woodbury granite occurs in numerous outcrops within an area about 3½ miles square occupying the northeastern part of the town of Woodbury. The principal quarries are on the southeast flank of Robeson Mountain where several types of dark to light bluish gray biotite granites occur. Most of them are porphyritic in texture, with large, scattered feldspar crystals. The products are known to the trade as "Woodbury Gray," "Imperial Blue," "Woodbury Bashaw," and "Vermont White." They are used for both building and monumental purposes. Woodbury has produced more building granite than other Vermont quarries, except possibly those at Bethel.

The Cabot granite is dark bluish gray and of fine, even-grained texture. It is used for monuments and markers. Quarries at Calais, or more properly at Adamant, are in a ridge of attractive fine-grained, light gray biotite granite sold as monumental stone.

Windham County.—The source of Dummerston granite is a dome about 1 square mile in area which rises approximately 900 feet above West River, about 5½ miles from Brattleboro. Sheeting planes 6 inches to 2 feet apart, in a zone 25 to 35 feet thick with much more widely spaced sheeting planes both above and below, are an unusual feature. Major joints strike N.15°E. and are 7 to 30 feet apart. Rift and grain are pronounced, the former being vertical, with a N.15°E. course, and the latter horizontal. There are two main types of granite, the better known being the "Dummerston White," an even-grained, light gray rock speckled with bronze mica, which is used for building, monuments, paving stones, and curbing; the second type is a light bluish gray rock employed for monuments.

Windsor County.—The best known Windsor County granite is quarried at Bethel, on Christian Hill, a dome at least one half mile long, 550 to 650 feet wide, and 350 feet high. The rock is a bluish or milk-white muscovite granite, of medium to coarse texture. Sheeting planes are 6 inches to 8 feet apart. Major joints are variable but follow a general east-west direction. The rift is horizontal or dips eastward slightly, and the grain is vertical, with a nearly east-west course in the largest quarry. "Bethel White" is used for both monumental and building purposes but is particularly adapted for the latter. The Union Station and the Post Office at Washington, D. C., were made of this stone. It is one of the whitest granites quarried and is often mistaken for marble.

A light greenish gray muscovite granite, well-adapted for building, occurs near Rochester. "Plymouth White," "Windsor Granite," and "Ascutney Green" are commercial types found near Plymouth and Windsor.

Massachusetts.—Massachusetts ranked second as a producer of dimension granite, with an output in 1928 valued at $3,749,668, or 15.2 per cent of the total for the United States. Corresponding figures for

1929 are \$4,005,083; for 1930, 3,024,669; for 1936, \$2,003,302; and for 1937, \$1,956,408. Unlike Vermont producers, who specialize almost exclusively in monumental stone, Massachusetts quarrymen diversify their production. Of the 1928 production 45.5 per cent was building stone, 24 per cent monumental, 10.2 per cent paving stones, 18.9 per cent curbing, and 1.4 per cent rubble. During recent years a gradual increase in the proportion of building stone has been noted. There are several important producing centers, notably Quincy, Milford, West Chelmsford, and Rockport, as well as quite a number of less productive areas scattered throughout the State.

Berkshire County.—The more important granites of Berkshire County occur near Becket. The rock is a fine-grained, bluish gray muscovite-biotite granite with a tendency toward gneissic structure. Two main types are marketed as memorial stones, "Chester dark" and "Chester light," the variation in color being due to differences in the proportion of biotite present. Sheeting planes are 6 inches to 30 feet apart and thicken gradually with depth. Joints are in two prominent systems, which intersect at right angles. Gray granite has been quarried at Otis.

Bristol County.—Important deposits of rock in two colors occur near Fall River in southeastern Massachusetts. "Fall River Pink" is a pinkish gray, gneissoid, biotite granite; "Fall River Gray" is similar, except that it is light buff-gray. Both are suitable for rough, massive construction and for curbing. Sheets are 1½ to 16 feet thick, and joints are spaced 20 to 200 feet apart. Pegmatite, aplite, and basic dikes occur in places, and black knots in the form of inclusions are not uncommon.

About 2 miles northwest of New Bedford is a deposit of substantial and attractive building granite. The "New Bedford" is a light pinkish gray biotite-muscovite granite gneiss of coarse texture, cut by an unusual series of dikes, including diorite, diabase, and pegmatite. Rough and dressed building stone, paving blocks, and curbing are the chief products.

"Dartmouth" granite is quarried about 8 miles southeast of Fall River. It is similar to the New Bedford stone, except that it is light buff-gray. The sheets are 1 to 12 feet thick, the rift is horizontal, and the grain is vertical. It is used for rough construction and curbing.

Essex County.—An olive-green hornbende-augite granite somewhat resembling that quarried at Quincy is found in the Peabody-Lynnfield district, southern Essex County. The rock, known to the trade as "Peabody Green," is used for trimming, base courses, steps, curbing, and paving stones.

The most important granites of the county occur on Cape Ann, at the extreme east. The entire cape is made up of granites and related rocks, though they are covered in part with sandy hillocks, flats, and marshes. Rockport granite is of two main sorts—gray and green. The grays are abundant and are known commercially as "Rockport Light

Gray," and "Bayview Gray." The latter is a medium- to coarse-grained, black-spotted gray hornblende granite which is rather hard to work because of a high content of free quartz. The second type, known as "Green Granite" or "Seagreen," is a dark, black-spotted, olive-green hornblende granite. As already stated, a conspicuous feature of the Rockport quarries is the large number of basic dikes which traverse them. Pegmatite dikes and black knots are not uncommon. The rift is generally east-west and vertical, and the grain horizontal. Sheets are 6 inches to 35 feet thick. Numerous joints intersect at various acute angles. The rock is adapted to a variety of uses. As the location of the quarries at tidewater is a great advantage for shipping many large blocks are quarried for docks and other types of heavy shore-line construction. The granite is also used for rough and dressed building stone, rough and dressed monumental stone, paving blocks, curbing, and rubble. The two large fountains on the Union Station plaza, Washington, D. C., are made of the sea-green stone.

Hampden and Hampshire Counties.—A fine-grained, dark gray, quartz-diorite gneiss found near Monson is used chiefly for building and curbing. The banding is attributed to flow structure rather than to metamorphism. A gneissoid granite similar to the Monson, quarried in a small way at Pelham, has been used principally for local building.

Middlesex County.—A light bluish gray biotite-muscovite granite gneiss (more properly a quartz monzonite), quarried near Acton, is used chiefly for building and curbing. Coarser grained granites from the vicinity of Groton are used chiefly for paving stones.

Important deposits occur near Graniteville, Westford, West Chelmsford, and Lowell. The "Oakhill," from the neighborhood of Westford, is a light bluish gray muscovite-biotite granite gneiss. It is medium-grained and slightly porphyritic. Sheets are 8 inches to 12 feet thick. Joints are in three main systems intersecting at oblique angles. The rift is horizontal and the grain vertical. The best-quality rock is used for monuments and dressed building stone, and the coarser and less uniform material for bridges, rough building stone, paving blocks, curbing, and rubble. The "Graniteville" is similar, though generally lighter in color. About a dozen companies, some with extensive quarries, operate in the West Chelmsford-Westford district. The largest quarry at West Chelmsford is about 1,500 feet long, 500 feet wide, and 100 feet or more deep. Sheeting planes are horizontal, and sheets are progressively thicker at depth. Vertical joints are widely spaced. The quarry is exceptionally well-equipped for production of building stone, curbing, and paving stones.

Norfolk County.—The granite industry in the neighborhood of Quincy is one of the most important in the United States. The rock occurs 7 or 8 miles south of Boston in the Blue Hills, a ridge which attains

a maximum height of about 640 feet. The quarries are in a lenticular area about 10 miles long from east to west, and one half to 2 miles wide. The rock is of unusual composition, being described as a riebeckite-aegirite granite. Riebeckite and aegirite are varieties of amphibole and of pyroxene, respectively, both rich in soda and iron but low in alumina, magnesia, and lime. Average Quincy granite consists of about 60 per cent feldspars, 31 per cent quartz, and 9 per cent riebeckite and aegirite. Unlike most granites it contains no mica. In color it ranges from medium or greenish gray to dark bluish gray. The bluish shades probably are due to the presence of the riebeckite and the greenish color to the aegirite. It is a medium- to coarse-grained rock of uniform texture and is noted for its ability to take a high polish. The darker varieties are marketed, chiefly as rough monumental stone, to manufacturers who distribute it to retail monument dealers in all parts of the country. The various trade names are "Quincy Medium," "Quincy Dark," "Quincy Extra Dark," and "Goldleaf." The last is the lightest shade of monumental stone sold, and is characterized by yellowish and reddish specks of iron oxide derived in part from oxidation of the unusual mineral, aenigmatite. "Extra Light" or "Pea-Green" are even lighter colored varieties, used principally for building.

Sheet structure is well-defined in places, the planes ranging in spacing from 6 inches to 27 feet. The sheets consist of lenses with an undulating course, usually parallel to the rock surface, and with increasing thickness at depth. Planes have been found at a depth of 250 feet. In other parts of the deposit the sheeting is obscure and irregular. Joints are in several systems, meeting at various oblique angles. As their course is followed downward many disappear, and new ones may appear at various levels. Such discontinuity is characteristic of the Quincy district. The spacing of joints is very irregular, ranging from 1 or 2 to over 100 feet. Another unusual feature is the presence of rift and grain, both in vertical directions. Generally the course of the rift is from N.65°W. to west, and the grain is about north and south, though there are exceptions. Frequently the grain is obscure. Trap dikes and black knots occur in places.

The Quincy granite industry first became important in 1825, when stone for Bunker Hill monument was quarried. For many years five to eight companies have been in operation, and the annual value of their combined product has been $370,000 to $675,000.

Granite is produced in several places in Norfolk County outside the Quincy district. In the extreme east, near Cohasset, a mottled yellowish gray granite of coarse texture is quarried for monuments and church interiors.

At Weymouth, south of Quincy, a gray granite is sold for decorative ashlar and rough masonry. The walls of the closely spaced joints are

stained yellow and brown, providing variegated colors for seam-faced stone now so popular with architects. A coarse-grained gray stone quarried near Stoughton is used for local building. A light gray, medium-grained hornblende granite from Wrentham is used for building and curbstones.

Plymouth County.—At Hingham, in the northeastern part of the county, a greenish gray aplite is quarried for building purposes. Few sheeting planes occur, but joints are numerous and closely spaced. As the rock is stained to a rusty color in the numerous seams it is not suitable for monumental work but fulfills modern demands for decorative building admirably. Like the rock near Weymouth, described in the preceding paragraph, it is marketed as seam-faced granite and has been used in many notable buildings. Stone for similar uses is obtained near Lakeville in the southern part of the county.

Worcester County.—The most important granite district of Worcester County is near Milford, about 16 miles southeast of Worcester. Between 15 and 20 quarries have been opened in various parts of this extensive deposit. The Milford rock is a light pinkish or greenish gray biotite granite characterized by black spots of mica. It is of medium to coarse texture, with a slight tendency toward banding or parallelism which is attributed to flow structure. When the rock is cut parallel with the flow structure the black spots are largest, because the mica flakes parallel this direction. Another characteristic feature is the blue color of the quartz grains. The rock is cut by diorite, aplite, and porphyritic granite dikes. Black knots are present in places, some being inclusions and some segregations. Sheeting planes are 6 inches to 18 feet apart. Joints are in three main systems N.10°E., N.45°-60°E., and N.55°–70°W.; though they are also found in other directions. The rift is uniformly horizontal and the grain vertical, ranging in direction from N.40°E. to east-west. "Milford Pink," the prevailing commercial type, has a pleasing color, either with tool-dressed or polished surface, and is particularly effective for carved or other architectural work. It has been used in many large buildings in the Eastern and Middle Western States, notably in the Pennsylvania Railroad station in New York.

At Uxbridge, about 8 miles southwest of Milford, a light gray, medium-textured biotite granite gneiss, useful for construction purposes, is quarried. Though sheets are absent, joints are numerous. Alteration or staining from the joint surfaces forms the so-called "sap" rock to a depth of a foot in places. The stone is used for rough construction, dressed building stone, curbing, and rubble and to some extent for monuments.

Near Fitchburg in the northern part of the county a light bluish gray muscovite-biotite granite gneiss is quarried for building stone, paving blocks, and curbing. A little rough construction stone is obtained at Holden, near Worcester.

Minnesota.—Minnesota, which ranked third in production, has deposits of high-grade granites of several distinctive types. The major part of the industry is centered near St. Cloud, in Stearns and Sherburne Counties, about 60 miles northwest of Minneapolis. St. Cloud ranks second as a national monumental granite center, being exceeded in value of output only by Barre, Vt.

The value of dimension granite produced in Minnesota in 1928 was \$2,637,704, or 10.6 per cent of the total for the United States. Corresponding figures for 1929 are \$3,226,665; for 1930, \$2,648,909; for 1936, \$1,205,688; and for 1937, \$883,179. Building-granite production is a much more important industry in Minnesota than in Vermont, as about 40 per cent of the output is used for construction and 60 per cent for monumental purposes. Paving-block and curbing production have become almost negligible in recent years.

Minnesota granites occur in two main districts. Those usually classed as of lower Keweenawan age outcrop in many parts of central Minnesota, notably in Stearns, Sherburne, Benton, Morrison, and Millelacs Counties; in the southwestern part of the State, along the Minnesota River Valley from New Ulm to Ortonville, those of Archean age occur. Granites appear in other counties but are not considered here, as they are utilized to a very limited extent as dimension stone. Recently a small production of monumental and rough building stone has been reported from St. Louis County in the far north.

As the granites occur in two distinct areas it seems more logical to consider each separately than to discuss the occurrences alphabetically by counties.

St. Cloud District.—Granites occur at or near the surface over an area of about 200 square miles near St. Cloud, "the Granite City." The most active quarry region, in which 25 to 30 companies operate, is 3 to 4 miles west and southwest of the city. Many well-equipped mills for cutting and polishing are situated in St. Cloud; and, unlike those of the Barre district of Vermont, most of the mills are operated by quarry owners. Therefore Minnesota products enter the market as cut or dressed stone, whereas much of the Vermont production is sold in rough blocks. On this account, the unit value of the Minnesota stone is much higher than that of the Vermont product.

The rock is of three main types, "St. Cloud Red," "St. Cloud Gray," and "Rockville." The red granite is medium- to coarse-grained, the feldspars averaging about one fourth inch in diameter. These minerals, which constitute about 75 per cent of the rock, consist of orthoclase and microcline with a smaller amount of plagioclase. Quartz, forming about 15 to 20 per cent of the rock, occurs in coarse glassy grains. Hornblende and biotite form 5 to 10 per cent. The rock is deep red, is very attractive when polished, and is therefore used chiefly for monuments. The gray granite consists principally of orthoclase, plagioclase, hornblende, and

quartz, the last mineral being much less prominent than in the red granite. It is used chiefly for monuments, though a subordinate amount is used for paving blocks and curbing. "Rockville" is much coarser-grained than the red and gray types, the feldspars being one half to three fourths inch across. It is a pinkish gray biotite granite, consisting of feldspar, chiefly orthoclase, quartz in large glassy grains, and black mica. Though used for monuments to some extent, it is essentially a building granite.

The deposits are cut by granite, aplite, and trap dikes. In many places red granite dikes cut the gray, while the converse is never found, indicating that the red granite is a later intrusion. Aplite dikes are common, especially in the gray granites. Diabase or trap dikes, occurring in many places throughout the region, range in width from a fraction of an inch to 6 or 8 feet. Hair lines of various types are present. Black knots, both segregations and inclusions, are not abundant but are frequent enough to be troublesome. As stated earlier, joints are well-developed, usually in two major systems, one running approximately north and south and the other east and west. They are spaced at convenient intervals for quarrying, usually 2 to 12 feet apart. Sheeting planes are scarce or entirely absent, a circumstance which makes quarrying difficult. The rift is horizontal and the run vertical, ordinarily north and south.

Stearns County.—The chief quarry district is in western St. Cloud township, where 15 to 20 quarries are in operation. Both red and gray granites are quarried. The rock occurs in a series of low domes which may be worked as shelf quarries of shallow depth, but most of the quarries are deep enough to be of the pit type. The rift and run are more pronounced in the gray than in the red, on which account the former is better adapted for paving stones and curbing. For monumental uses the deep reds are more desirable. Quarrymen have their own special trade names, among which may be mentioned "Rose Red St. Cloud," "Indian Red St. Cloud," "Victory Red St. Cloud," "St. Cloud Superior Red," "Red Rock," "Melrose Red," "Minnesota Mahogany," "Black Diamond Red," "Red Pearl," "North Star Red," "St. Cloud Gray," "Victory Gray St. Cloud," "St. Cloud Superior Gray," "Melrose Gray," "Pioneer Gray," "Royal Gray," and "Dark Gray." The granites are much in demand and are widely marketed, even in States far from the quarries.

The Rockville district is about 10 miles southwest of St. Cloud in a pale pink coarse-grained granite of exceptionally uniform texture and color. The rock rises in a dome which is exposed over at least an acre. Open joints are far apart and somewhat irregular in direction. The most prominent strike N.70°W.; others strike N.45°E., N.55°W., and N.10°W. If joints were closely spaced, this irregularity would result in much

waste rock, but here where they are spaced 20, 40, and even 100 feet apart the irregularity has little consequence. In fact, quarrying would be much easier if they were spaced more closely. There are also few sheeting planes. The rock is so uniform and so free from defects that very little waste results. "Rockville" granite is an attractive structural stone, for the cleavages of the coarsely crystallized feldspars give a glittering reflection on the hammered surface. It is also well-suited for carving, but is used to a limited extent for monuments. The granite is quarried by two long-established companies and is sold under the trade names "Minnesota Pink" and "Minnesota Pearl Pink." It has been used in many notable buildings, for example, in the cathedral at St. Paul, Minn.

Sherburne County.—Granites are available only in the northwest corner of Sherburne County. Though red and some intermediate varieties are present, gray predominates. The gray rock has a horizontal rift and vertical run (grain) north and south. Black knots and aplite dikes occur in places. Most of the joints are widely spaced. In some quarries sheeting planes are 4 to 16 feet apart; in others few are encountered. The rock is adapted chiefly for building and for paving blocks. One large quarry is operated by the State reformatory, and the rock is used for construction of the main building and walls. Several companies operate in both red and gray granite, producing building stone, paving blocks, curbing, and monument stock. During recent years, however, paving and curbing manufacture have decreased greatly. "Minnesota White" and "Hilder Gray" are common trade names.

Benton County.—Outcrops are more numerous in Benton than in Sherburne County, but the rocks are less uniform and present a greater diversity of types. The most abundant rock is a dark diorite some of which has been used for building stone, paving blocks, and monumental stock.

Mille Lacs County.—On the west branch of Rum River a few miles west of Milaca a red granite is quarried for monuments and sold under the name "Sunset Red." Most of the rocks in the county are diorites and are not attractive for high-grade work.

Morrison County.—A granite of the "St. Cloud Red" type is quarried near Glenola for manufacture of monuments. A dark, fine-grained rock quarried near Little Falls is described as an augite-diorite, consisting of numerous lathlike crystals of plagioclase, biotite, green hornblende, and almost colorless augite. It is marketed as a black granite under the trade name "Little Falls Black."

The Granites of the Minnesota River Valley.—Thousands of years ago an immense volume of water derived from melting ice sheets and from rainfall over an area that may almost be termed continental poured down the valley of what is now the Minnesota River. In its passage it swept

away all decayed and weathered débris and eroded a valley 2 miles wide in places, a valley entirely out of proportion in magnitude to the small river that now flows through it. Ancient Archean rocks ordinarily protected by a covering of Cretaceous sediments, are exposed in this valley; and not only have overlying formations been removed, but the scouring effect of the great river has swept away the upper zone of weathered granite, leaving the rock fresh and unaltered at the surface. Both granite and granite gneiss outcrop in many places, and have been quarried at various points between Odessa and Morton.

Big Stone County.—There are numerous outcrops near Ortonville, Odessa, and Correll. The "Ortonville" stone is a deep red biotite granite or granite gneiss, which takes an excellent polish. In quarrying, much waste results from the presence of pegmatite dikes, black knots, and closely spaced or irregular joints. Monumental stone and ornamental columns sold as "Ruby Red" have been obtained from these deposits.

Redwood and Renville Counties.—The best rock in these counties occurs in outlying masses in the Minnesota River Valley. These are prominent domes at North Redwood and across the river from Morton; near the latter town a dome covers many acres and reaches an elevation which affords an extensive view of the river basin from its summit. The rock exhibits little or no weathering, even at the surface. Two types are available near North Redwood—one a medium-grained, greenish gray biotite gneiss, and the other a pale pink biotite granite or quartz diorite. Both rocks are even-grained and are exceptionally attractive for monumental and building uses. A type known as "Rainbow" granite is well known in the monument trade.

The rock near Morton is a biotite granite gneiss with distinct banding. Although of uneven texture it takes a good polish, and about half of the production is suitable for monumental stone. It is also used for monument bases, curbing, building stone, and bridge construction. It is very strong, even in a direction parallel to the banding. Sheeting planes are 12 to 20 feet apart and dip 5 to 15°, always toward the margin of the dome. Major joints are 6 to 30 feet apart, in systems approximately at right angles. Black knots and streaks are present in places. The strength of the rock and its availability in large sound blocks make it particularly suitable for heavy construction.

North Carolina.—The value of block granite produced in North Carolina in 1928 was $2,253,435, or 9.1 per cent of the total for the United States. As in Massachusetts, the production is diversified; 43.7 per cent of the total for the year was building stone, 15 per cent monumental stone, 13.7 per cent paving blocks, 26.2 per cent curbing, and 1.4 per cent rubble. Building granite has become increasingly important in North Carolina since 1926, the growth in volume being due to the increased use of ashlar granite in medium-priced dwellings. So much of

the production was "undistributed" in the years 1929 to 1937 that figures obtainable do not give a true picture of the extent of the industry.

Granites and gneisses are distributed widely in the State, being found in all three of the larger geologic provinces—the Coastal Plain, the Piedmont Plateau, and the Appalachian Mountains. Those that have been used most are in the Piedmont Plateau region.

Granites occur in several counties of the Coastal Plain in the region bordering the Piedmont Plateau, and are extensions of the crystalline rocks of the latter region beneath the Coastal Plain sediments. They range from fine even granular to coarse porphyritic in texture and from gray to pink in color. Most of them are biotite granites. Joints are well-developed in three main systems, northwest, north, and northeast. Diabase dikes are of common occurrence.

Much stone of good quality is readily available within the limits of the Piedmont Plateau. Numerous quarries have been worked over many parts of this region, which has been divided geologically into four belts. The northeastern area, including Wake, Franklin, Vance, Granville, and Warren Counties, borders the Coastal Plain. Most of the granites in this section are schistose and therefore have limited commercial value. In certain areas, however, granites of good quality for building purposes have been worked for many years. The next belt to the west consists of slates, schists, and altered volcanic rocks, with little or no granite of commercial value. West of this is the central belt, including Mecklenberg, Gaston, Cabarrus, Iredell, Rowan, Davidson, Davie, Forsyth, Guilford, and Alamance Counties, where biotite granite is one of the principal and most widespread rocks. It occurs in each of the 10 counties mentioned and has been quarried from time to time, usually to satisfy local demands. Two distinct types occur, an even granular rock and a porphyritic granite, much of which shows evidence of gneissic or schistose structure. Colors range from white to various shades of gray and occasionally pink. The western belt includes Surry, Wilkes, Alleghany, Alexander, and Cleveland Counties, with greatest development in Surry County. This area is well-supplied with railway lines, which greatly aid marketing. The commercial granites here are in the form of igneous intrusions of both massive and schistose types.

The Appalachian belt is mountainous, and quarrying has been confined chiefly to a few areas of gneiss suitable only for crushing or for rough construction. In Madison County an area of mixed dark green and yellow biotite-epidote granite should prove of economic value.

The commercial granites will be considered in the three geologic provinces in succession:

Coastal Plain Granites. WILSON COUNTY.—Only small areas of granite are exposed in Wilson County, the more important about 3 miles north and 3 miles south and southwest of the town of Wilson. During recent

years the latter area, with exposures on both sides of Contentnea Creek, is the only one quarried. The rock is coarse-grained, pinkish red and of porphyritic texture. It is used for bridge construction and rough building.

While granites occur in other Coastal Plain counties little or no block granite has been produced in late years.

Piedmont Plateau Granites.—SURRY COUNTY.—The most important granite district of North Carolina is near Mount Airy in Surry County near the northern boundary of the State. Originally the outcrop was a dome rising about 125 feet above the valley, but much of the upper part has been removed. The surface area, now exposed partly as a natural outcrop and partly by stripping, covers about 70 acres. The rock is a very light gray, almost white, biotite granite of medium texture. The biotite is unequally distributed; some masses contain little or none, in consequence of which they are exceptionally white. For the most part, however, the rock is of uniform color and texture. Veins and dikes, so common in most granites, are nowhere evident in the Mount Airy deposit. Absence of joints and sheeting planes is the most remarkable feature, the rock being massive throughout, with no natural partings. It has a horizontal or slightly dipping rift and a vertical grain—structural features of the utmost importance in quarrying and manufacture.

Production has grown steadily since 1890, when the rock was first quarried. Operations are now more extensive than in any other district south of New England. The rock has exceptional merit for building purposes and for mausoleums, as it is light in color and pleasing in appearance, and also for bridge work, as sound blocks of any desired size are obtainable. Granite from this deposit valued at $1,500,000 was used in the Arlington Memorial Bridge over the Potomac River at Washington, D. C. shown in the frontispiece. It has been employed in many large structures throughout a wide market area extending to Philadelphia, New York, and more distant cities. Although the chief market is for cut stone used in bridges, dry docks, and large buildings, quite an extensive market has been developed recently for the smaller fragments in the form of ashlar for constructing moderate priced dwellings. Such material is being shipped as far north as eastern Pennsylvania. Mount Airy granite is also well-adapted for the manufacture of paving stones and curbing, and the latter use accounts for about one fourth of the total production value. It is less suitable for monuments, as the color contrast between cut and polished surfaces is not decided enough. Both quarries and mills at Mount Airy are equipped with the most modern machines and appliances.

ROWAN COUNTY.—Next in importance to the Mount Airy granite are those found near Salisbury, Rowan County. The rock rises in a nearly continuous ridge, beginning about 4 miles east of Salisbury and extending

southward more than 12 miles. In the northern part two distinct types occur, a very light gray or nearly white rock, and a pink or flesh-colored granite. They are of identical texture and mineral content and evidently parts of the same intrusion. In the pink rock quarried near Granite joints are in two systems striking N.10°E. and N.70°W., and are spaced widely enough to permit quarrying large blocks. Sheeting planes are 2 to 8 feet apart. The rock is notably free from veins or dikes, is medium-grained, uniform in texture, and attractive in color. It is sold both rough and dressed and is popular as a monumental stone marketed under the trade name "Balfour Pink."

In the gray rock, also quarried near Granite, joints are less systematic than in the red but are widely spaced. The stone has good working qualities and dresses well under the hammer. It has been used widely as a building stone and for curbing and paving but little for monuments. Similar granites, both gray and pink, are quarried near Faith, 5 to 9 miles south and southwest of Salisbury.

DAVIDSON AND WAKE COUNTIES.—Gray granites of various types occur in Davidson County, but in recent years they have been quarried only in the vicinity of Southmount and used chiefly for paving blocks. In the vicinity of Wake Forest in the northern part of Wake County a medium- to fine-grained, light gray biotite-muscovite granite is quarried for building, curbing, paving blocks, and rubble.

Appalachian Mountain Granites. HENDERSON COUNTY.—A medium-grained, light gray biotite gneiss occurs near Hendersonville. It is of uniform color and texture, though a few black knots occur in places. Large blocks are obtainable. Most of the granite quarried in Henderson and in Buncombe County to the north is used for crushing, though it is used to some extent in rough construction.

Maine.—The value of granite in the form of dimension stone produced in Maine in 1928 was $2,249,715 or 9.1 per cent of the total for the United States. Paving stones, which represented 54.8 per cent of this amount, are the chief products. Maine produced more than 42 per cent of all the granite paving blocks in the country. The value of building stone was 25.2 per cent, monumental stone 6.9 per cent, curbing 12.9 per cent, and rubble 0.2 per cent of the total. There is evidence of a trend toward a larger percentage of building-granite production, as the location of quarries at the coast is favorable for water transportation to New York and other coast cities, where it is gaining in popularity. Production in 1929 was valued at $2,630,266; in 1930, $2,039,058; in 1936 $1,212,855; and in 1937, $1,280,122.

Granite is distributed widely in Maine; in fact, it is the most abundant rock. It occurs in three main areas—in the western tier of counties, along the eastern coast, and in the Mount Katahdin area in the north-central part. In addition, there are three small areas in Lincoln, Ken-

nebec, and Somerset Counties. Except for important centers at Hallowell, Kennebec County, North Jay, Franklin County, and several developments of minor importance, all quarries are along the seaboard, either on or within a few miles of navigable waters. The industry is centered in Penobscot and Bluehill Bays and the islands in or adjacent to them. Occurrences now of commercial importance will be described by counties in alphabetical order.

Cumberland County.—A fine, even-grained gray biotite granite is quarried about 3½ miles northeast of Westbrook. It has a distinct flow structure which gives it the appearance of a gneiss. Sheeting planes are 6 inches to 2½ feet apart and nearly horizontal. Joints are few, and the rift is horizontal and grain vertical, striking eastward. The rock is used for monuments and curbing.

Franklin County.—An important granite center of the county, particularly for building granite, is at North Jay. The rock, a light gray biotite-muscovite granite of fine, even-grained texture, is known to the trade as "North Jay White." The whiteness is due to the quartz being clear, not smoky as in many granites, and to the light color of the feldspars visible through the quartz, as well as on the surface. The sheets are 4 inches to 6 feet thick, being quite thin in the upper 25 feet and gradually thickening at increasing depths. The chief joints run N.62°E., N.70°E., and N.50°W. and are widely spaced. The rift is horizontal, and there is no grain. Black knots are rare, but a few pegmatite dikes are present. The rock is exceptionally attractive for building, though it is also used extensively for monuments, mausoleums, paving stones, and curbing. Though one of the few important granite centers of Maine distant from tidewater, it has direct rail connection, and its products are widely employed not only in New York, Philadelphia, and other eastern cities but also throughout the Middle West.

Hancock County.—More granite is produced in Hancock than in any other county in Maine. Over a dozen quarry companies operate near Franklin. The rock is a medium- to coarse-grained, gray biotite granite, of uniform texture. Sheeting planes are 2 to 13 feet apart. For the most part, joints are widely spaced. The rift is horizontal and grain vertical, usually striking east-west. Black knots and trap dikes are not unusual. Paving blocks, curbing, and monument bases are the chief products.

A light buff to gray biotite granite of medium to coarse, even-grained texture is quarried near Mount Desert. The four chief minerals—buff orthoclase, milk-white plagioclase, smoky quartz, and black biotite—present very attractive color contrasts which are enhanced by polishing. In one part of the deposit the rock is pinkish gray and is marketed as "Sommes Sound Pink." Sheets are 2 to 12 feet thick. Widely spaced major joints strike N.25°W., N.50°E., and N.85°E. The rift is horizontal,

and grain vertical, usually striking east-west. Dark gray knots up to 6 inches in diameter occur in places. The quarries are close to tide-water, and the wharves are accessible to schooners of 20-foot draft. Building stone, monument stock, and paving stones are the chief products. The stone has a wide market and has been used in many important structures.

Another important quarry district covers an area of about 4 square miles around Stonington, including parts of Deer Isle and Crotch Island. On the southern half of the latter island the rock rises in a dome about 140 feet above sea level. At its center the sheets are horizontal but dip downward at angles of 10 to 25° toward both the northwest and the southeast. East-west vertical joints are prominent. The Crotch Island rock, a coarse, even-grained, gray biotite granite with lavender tint, is well-suited for massive construction. Its polished surface shows pleasing contrasts, and on this account it is in demand for base courses, wainscoting, and monuments.

An important deposit of similar granite occurs on Deer Isle and is quarried about 2 miles from Stonington. Sheets are 6 inches to 16 feet thick and dip 10 to 15° north and south, away from the top of the hill. Joints are widely spaced, the rift is vertical and runs N.60°–65°W., and knots are rare and small, but granite dikes 4 to 12 inches thick occur in places. The stone is used widely for massive construction, such as for piers, sea walls, and bridges and also in many large buildings.

Near Sullivan a fine- to medium-grained, uniform gray biotite granite is quarried. The sheets in one quarry are 3 to 8 feet thick. Joints strike N.80°–85°W. and N.10°–20°E. There are many black knots. In another quarry the sheets are only 1 to 5 feet thick. A coarse- to medium-grained gray granite is also quarried in this district. Paving blocks and curbing are the chief products. Similar granites are quarried for monument bases, paving blocks, and curbing near North Sullivan.

Kennebec County.—An important inland stone-producing district near Hallowell is one of the oldest in the country, the quarries first having been opened in 1826. Though a considerable distance from the coast, they are only 2½ miles from a wharf on the Kennebec River and are accessible to schooners of 12-foot draft. The well-known, fine-textured, light gray "Hallowell granite" consists essentially of feldspar, quartz, biotite, and muscovite. The most striking structural feature of the quarries is the gradual increase in thickness of the sheets downward, from 4 inches to 14 feet. Joints are spaced more closely than in many New England granites and intersect the rock at various angles. The rift is horizontal, and a poorly developed grain vertical, striking N.25°W. Black knots occur in places, and sap rock bordering the joint planes may be a foot deep. The stone is widely used for building purposes, where it is particularly adapted to carving, and also for monuments and paving stones.

Knox County.—The principal quarries of Knox County are near Long Cove, St. George, and South Thomaston, south and southwest of Rockland, and on Vinalhaven Island. In the former region most of the rock is fine- to medium-grained and blue-gray. Sheeting planes are 2 to 13 feet apart and usually dip at small angles. Joints vary in direction and are closely spaced in places. The rift is vertical, with a general east-west course. Many paving blocks are made and as the stone takes a good polish it is popular also for monuments.

Vinalhaven and the adjacent islands have been known as the Fox Islands, and their granite as "Fox Island Granite." Many quarries have been operated at various times, chiefly near Vinalhaven Island and on Hurricane Island. During recent years two companies have been responsible for the chief production. Much of the rock is pinkish buff and coarse textured, but some quarries produce a fine, even-grained, gray granite. In this rock sheets are 1 to 6 feet thick; vertical joints strike N.80°W. and N.5°–10°E. The rift is vertical, striking N.5°–10°E. In the coarse rock, sheets are 2 to 10 feet thick, and the joints are in several intersecting systems. Although building stone has been produced from these quarries, recent production has been confined principally to paving stones. An attractive black granite is quarried at Vinalhaven.

Lincoln County.—A fine-grained dark gray quartz diorite, classed commercially with the "black granites," is quarried near Round Pond for monuments and paving blocks. Sheets are 1 to 12 feet thick. Major joints striking N.60°E. are 5 to 40 feet apart, and a second system N.40°W. is at wider intervals. The rock is cut by both pegmatite and trap dikes. It takes a good polish and shows marked contrast between tooled and polished surfaces.

Somerset County.—A light gray, even-grained granite with a distinct flow structure has been quarried at several points about 2½ miles south of Norridgewock. It is used for both buildings and monuments.

Waldo County.—A fine- to medium-grained, light gray, muscovite-biotite granite is quarried near Lincolnville, chiefly for monumental use. The sheets are 6 to 15 feet thick and dip 25°S. The chief joints strike N.60°–65°W. The rift is vertical and parallels the major joints. Quarries at Mt. Waldo near Frankfort, which had been idle 25 years, were reopened in 1930 and equipped to produce building granite on a large scale. The rock is a fine, even-grained, gray biotite granite. Stone from these quarries was used extensively in the George Washington Bridge at New York. Water transportation on the Penobscot River is available.

Washington County.—Washington County granites are of two main types—"black granites" and medium-grained pinkish gray biotite granites. Some of the so-called black granites are norites but that quarried near Addison is a gabbro which polishes to a jet-black surface mottled with a little white, and one occurring near Calais is a dark gray

quartz diorite. As they all take a good polish, they are used for monuments. The pink granites, one of which is sold under the trade name "Back Bay Pink," quarried near Marshfield and Millbridge are used for monuments and building.

York County.—A coarse-grained, light gray granite occurs near Biddeford in sheets 1 to 15 feet thick. The rift is vertical, and the grain horizontal. It is used for monuments and rough construction. "North Berwick Black Granite" (gabbro) quarried near North Berwick is well adapted for monuments.

Georgia.—Block granite produced in Georgia in 1928 was valued at $1,985,838, or 8 per cent of the value of total production for the United States. About 26 per cent was sold as building stone; 21 per cent, monumental; 19 per cent, paving blocks; 33 per cent, curbing; and 1 per cent, rubble. Although fluctuations have occurred the trend in production was gradually upward from the World War until 1928. Production in 1929 was valued at $1,741,938; in 1930, $1,673,529; in 1936, $920,355; and in 1937, $875,529.

The granites of Georgia are entirely within the limits of the Piedmont Plateau, a northeast-southwest belt extending from the eastern base of the Appalachian Mountains to the Coastal Plain sediments occupying the middle-northern part of the State. Dimension stone is produced in three main districts—in the vicinity of Stone Mountain and Lithonia in De Kalb County, near Elberton in Elbert County, and near Sparta in Hancock County.

De Kalb County.—The most notable occurrence of granite in Georgia is Stone Mountain in eastern De Kalb County. It is a massive dome measuring 7 miles in circumference at its base and rising 686 feet above the adjacent lowlands. The rock is an even-textured, medium-grained, light gray muscovite-biotite granite of uniform color and texture. Joints in two well-defined systems, striking northeast and northwest are widely spaced, as are also the sheeting planes. The granite is well-adapted for building purposes and for bridges and mausoleums, as it is available in sound blocks of any desired size. Paving blocks, rubble, and a limited amount of monument stock are also produced. A wide market has been developed for the stone in Northern and Middle Western States, as well as in Atlanta and other adjacent cities. One large company has operated for many years on the flank of the dome.

A project to carve in massive proportions high on the cliff face a group of great Confederate generals has created much interest in Stone Mountain during recent years. The actual carving was begun in June 1923, but work was suspended 3 or 4 years later with the task far from completed.

In the Lithonia district the rock a fine-grained, highly contorted biotite granite gneiss, occurs in similar bosslike masses, though much

smaller than Stone Mountain. Red garnet and tourmaline are present in places, the latter mineral being associated with pegmatite dikes. In some quarries well-defined joint planes appear, while in others they are few in number. Sheeting planes are absent. The rock has a distinct rift and grain which are of great assistance in quarrying. Eight or ten companies have worked the deposits for many years. The chief products, paving stones and curbing, are sold in Atlanta and other southern cities and also shipped to many distant points. Rubble is produced as a byproduct.

Elbert County.—Granite is confined chiefly to the middle southwestern part of the county, though it extends into adjacent counties. In many places the rock appears in bare outcrop. There are two main types—a fine- to medium-grained, light gray, biotite granite and a dark blue-gray granite similar to the first, except in color. The former is best adapted for building purposes. The blue-gray granite is so uniform in texture and attractive in color and general appearance that it is used widely as monumental stone. Several companies operate in the district and market their products under various trade names, such as "Elberton Blue," "Oglesby Dark Blue," and "Oglesby Light Blue." Red or pink granites occur less commonly. One commercial variety is sold under the trade name "Sunset Pink." Railway facilities are available for shipment to many distant markets.

Hancock County.—The Hancock County granite area is about 11 miles long and extends northeast from Sparta. The rock occurs in bare outcrops, some several acres in extent. The prevailing type is a coarse-grained, medium gray, porphyritic biotite granite used for curbing, paving stones, and monuments.

Wisconsin.—The value of Wisconsin block granite produced in 1928, as reported to the United States Bureau of Mines, was $1,581,612, or 6.4 per cent of the value of total production of the United States. Nearly three fourths of the product in value is sold for monuments and one fourth for paving blocks. The proportion by uses was as follows in 1928: Monumental stone, 72.9 per cent; paving blocks, 24.9 per cent; building stone, 1.7 per cent; and curbing, 0.5 per cent. Production in 1929 was valued at $1,572,010; in 1930, $1,327,913; in 1936, $673,846; and in 1937, $794,578. Paving-stone production fluctuates greatly from year to year, with a general downward trend.

Igneous rocks underlie about one third of Wisconsin. Throughout this area granites of many colors and textures are found, and several distinctive varieties are marketed. Dark reds and reddish browns predominate, a condition that contrasts sharply with the prevailing grays of New England. The granites are described by counties in alphabetical order.

Ashland County.—A dark gabbro is quarried near Mellen. It takes a good polish and is sold for monumental and building uses as "black granite."

Green Lake County.—Rhyolite is quarried near Berlin, Green Lake County. Joints and sheeting planes are numerous and intersect at various angles, which results in the production of many small angular blocks, though large blocks are available. The rift is nearly horizontal and the "run" (grain) vertical. The rock polishes well on the run and hard way but not on the rift surfaces. It is dense and compact, of uniform texture, and generally grayish black. "Berlin rhyolite" is strong and durable and is used for monuments, paving blocks, and building stone.

Marathon County.—The widely known "Wausau Granite" outcropping at numerous places over an area of many square miles is quarried at Wausau and Granite Heights. The rock now quarried is not uniform in color but ranges from gray through reddish brown to brilliant red. Major joints are in two systems, striking approximately northeast and northwest. Sheeting planes are horizontal. Sound blocks of large dimensions are obtainable in most quarries, though in some places joints are less than 4 feet apart. It is used almost exclusively for monuments and sold under various trade names, such as "Wisconsin Mahogany," "Red Wausau," "Wisconsin Ruby Red," and "Parcher Green."

Marinetta County.—Granite in a variety of textures and colors is quarried along the Pike River near Amberg. Three distinct types are produced—a fine-grained, gray granite (Pike River Gray), a coarse-grained, red or pale pink (Amberg Red), and a coarse-grained gray. In general the joints are spaced far enough apart to provide suitable monument stock, but in some places are undesirably close together, or intersect at oblique angles. The rift is indistinct. In the past considerable building stone was produced, but during recent years monument stock is the chief product with a subordinate amount of paving stones. "Montrose Red" and "Marinetta Red" are other trade names applied to the products.

Marquette County.—High-grade granite is obtained from two mounds near and within the city of Montello. In the larger quarry, prominent joint systems strike N.85°E., N.25°E., and N.40°W. Many discontinuous parting planes break the rock into polygonal blocks, but masses of reasonable size for monuments are obtainable. Several greenstone dikes (trap) follow jointing planes. Streaks or hair lines which mar some of the rock are of two types, minute trap dikes and white quartz veins. The rock is a dense, fine-grained granite in two colors, a cheerful bright red and a grayish red. "Montello Granite" is a widely known, popular monumental stone. It takes a good polish and is attractive, but is difficult to work. Paving stones are manufactured, though not so extensively as in former years.

Waupaca County.—A coarse-grained or porphyritic biotite-hornblende granite of striking color and texture is quarried about 5 miles north of Waupaca. The two more important commercial types are "Red

Waupaca" and "Gray Waupaca." The former consists of large, bright pink feldspars surrounded by green epidote and chlorite, and the latter is a combination of paler pink feldspars, black biotite, and hornblende. Numerous, irregular joints cause much waste. Waupaca granite is well-suited for interior or exterior use in monuments or buildings. On account of its brilliant coloring it is particularly adapted for ornamental work, such as wainscoting and balustrades.

Waushara County.—A granite deposit at Lohrville and Redgranite in southeastern Waushara County presents favorable quarry conditions. Major joints strike N.30°–40°W. and N.75°–80°E. and are spaced at sufficient width to give large sound blocks. Sheeting planes 2 to 4 feet apart near the surface provide bench floors. A decided rift strikes N.50°E. Several coarse granite dikes traverse the deposit, and pegmatites, veins, and knots are present in some quarries, though in others they are absent. About 90 per cent of the rock consists of feldspar and quartz, with subordinate hornblende and muscovite. It is light pink (considerably lighter than the Montello granite), is of uniform, fine-grained texture, and takes a good polish. Three or four companies produce monuments, paving blocks, curbing, rubble, and rough construction stone.

New Hampshire.—In 1928 the block granite produced in New Hampshire was valued at $1,359,229, or 5.5 per cent of the value of total production in the United States. Distribution among the various uses in 1928 on the basis of value was as follows: Building, about 50 per cent; monumental, 19; curbing, 19; paving, 11; and rubble, 1. During recent years building stone has shown an upward trend in production, while that used for monuments has declined. Production in 1929 was valued at $1,063,112; in 1930, $1,411,084; in 1936, $293,540; and in 1937, $359,451. Granite production is confined chiefly to Carrol County in the east-central part of the State and to Cheshire, Hillsborough, and Merrimack Counties in the south. Gray, bluish gray, and various pinks are the prevailing colors.

Carroll County.—Building and memorial granites are produced near Redstone and Conway. There are two principal varieties—a coarse-grained, light pinkish gray biotite granite, "Conway Pink," and a coarse-grained, dark yellowish green biotite-hornblende granite, "Redstone Green." Though in contact, they represent originally different materials. Sheeting planes in the pink granite are 4 to 30 feet apart and arch across the axis of the hill. The most abundant joints strike east and west and are 5 to 40 feet apart. The rift is horizontal and the grain vertical in an east-west direction; they appear to follow sheets of microscopic cavities in the quartz grains. Pegmatites and black knots appear in places. In the green-granite quarry sheets are 11 inches to 14 feet thick and dip about

15°W. Joints, rift, and grain are the same as in the pink rock. Both varieties are used in buildings, as well as for polished columns and memorials.

Cheshire County.—A fine-grained, light bluish gray biotite-muscovite granite occurs near Fitzwilliam and Marlboro, adjacent to the southern border of the State. Estimated mineral percentages are: Quartz, about 44; feldspar, 46; and mica, 10. The granite takes a good polish and is well-adapted for fine carving. The rift is horizontal and the grain vertical, striking nearly east-west. In places pegmatite dikes and black knots are present. Near Marlboro the sheets are 6 inches to 6 feet thick, and joints are more plentiful than in the rock near Fitzwilliam, where neither sheets nor joints are well-developed. Stone from the latter district, sold under the trade names "Victoria White" and "Snowflake," is used for buildings and monuments. Paving stones are the principal products of the Marlboro quarries.

Hillsborough County.—Milford, where 10 or 12 companies are in operation, is the most important granite center of New Hampshire. "Milford Granite" is generally a fine, even-grained, gray rock of light and dark shades, some having a slight bluish, pinkish, or buff tinge. Although variable the major joints fall in a general way within two main quadrants, N.15°–50°E. and N.35°–80°W. In some quarries they are spaced only 3 to 5 feet apart but usually exceed 10 feet. The rift is generally horizontal and grain vertical, striking N.70°–80°W. In places trap dikes have altered the color of the granite. The stone takes a good polish, with marked contrast between cut and polished surfaces; it is also well-adapted for carving. Building stone, monuments, paving blocks, and curbing are manufactured. A fine-grained, buff-gray monumental granite closely related to the Milford rock is obtained near Brookline and South Brookline, that from the latter locality being marketed as "Brookline Blue."

Merrimack County.—An important deposit of fine-grained, medium gray muscovite-biotite granite occurs on Rattlesnake Hill near Concord. "Concord Granite" is used for cut building stone, monuments, paving, curbing, and ashlar. In one large opening typical of the district sheets are only 6 inches thick in the upper 30 feet but increase to a thickness of 40 feet at a depth of 130 feet. The joints, which strike N.62°E. and N.45°W., are few. The rift is horizontal and grain vertical, striking east-west. A few pegmatite dikes and quartz veins occur. Concord granite was used in construction of the massive edifice of the First Church of Christ, Scientist, in Boston, Mass. At Suncook, south of Concord, an even-grained, light gray granite, marketed as "Allenstown Granite," is used for building purposes, paving blocks, and curbing. It has been employed in many large buildings.

Minor Producing States

In preceding pages granites of the eight principal producing States have been described. Consideration will now be given to a group of eight States of less importance in this industry. Like the major producers, they will be considered in the order of their production in 1928.

New York.—The value of block granite sold in New York in 1928 was $948,991, which was 3.8 per cent of the total value of production for the United States. About 82 per cent was used for building purposes and 18 per cent for monuments. Since 1923 the building-granite industry of the State has grown rapidly, annual production value increasing from less than $50,000 to nearly $800,000. This increase is due partly to the demand for stone in the construction of the Cathedral of St. John the Divine in the city of New York; however the demand for building granite has decreased since 1928. Total production in 1929 was valued at only $301,486; in 1930, $497,576; in 1931, $430,042; and in 1932, $78,661.

Production in New York is restricted to two areas, the Adirondack region in the north and the Highlands in the southeast.

Adirondack Granites.—The most important northern granite occurs near Ausable Forks, Clinton County. Anorthosites (granitoid rocks, the essential mineral of which is plagioclase), syenites, and true granites occur in this district. Although the anorthosites and granites are very attractive, recent development has been confined chiefly to the green syenites. The typical syenite consists of about 75 per cent feldspars and 25 per cent other minerals, including pyroxene, magnetite, and zircon. It is medium-grained, is dark to yellowish green, takes a good polish, is attractive for monumental purposes, and is also used to some extent for building.

Attractive red granite is quarried on Wellesley and near-by islands in the Thousand Island district, Jefferson County. It is suitable for monuments and building purposes, but production has recently been confined to paving blocks only. A gray to pinkish type occurring near Alexandria Bay is also used in this way.

Granites of Southeastern New York.—The granite industry of Westchester County is becoming increasingly important. Stones of two types, light pinkish gray and a rich yellowish brown, are obtained from the Mohegan quarry about 3 miles east of Peekskill. The yellowish brown, one of the most attractive eastern granites for structural and monumental work, is widely used in New York City. Joint systems and other quarry conditions are favorable. Granite quarried about 1 mile to the south in the Millstone Hill district is gray to almost white and suitable for both building and monumental uses. At West Point, Orange County, dark-gray gneiss has been quarried for construction of the Military Academy buildings.

Near Yonkers a light blue to reddish granite with gneissoid foliation is obtained for rough construction work. Similar banded granites for rough building are quarried at various points near New Rochelle. Rock for building and monumental use occurs near the Bronx. Much of the granite in this area north of New York is useful as rock-faced ashlar for residential building.

California.—Production of block granite in California was valued at $620,790 in 1928. About one fourth was monumental and three fourths building stone. The value of building granite has fluctuated greatly. In 1925 it reached a high point of $1,200,000 but declined to less than one sixth of that amount in 1928. A large proportion is used in San Francisco and Los Angeles, therefore the demand depends to quite an extent on local conditions. Paving, curbing, and rubble production was very small in 1928 but increased greatly in 1929 and 1930. Total production in 1929 was valued at $1,560,314; in 1930, $1,047,256; in 1936, $247,967; and in 1937, $78,412.

During recent years granites for building and monumental uses have been produced in Fresno, Imperial, Madera, Nevada, Placer, Plumas, Riverside, Sacramento, San Diego, and Tulare Counties. A high-quality, medium-grained building and monumental granite, light gray specked with brilliant black mica crystals, is produced at Raymond, Madera County. It has been used widely in San Francisco for residences, hotels, banks, and State and Federal buildings and also quite extensively for monuments and mausoleums. The granite near Rocklin, Placer County, is light gray and of fine- to medium-grained texture; it is used for buildings and monuments, chiefly the latter. At Porterville, Tulare County, near Perris, Riverside County, and also in Fresno and Plumas Counties fine-textured, dark blue hornblende diorites classed as black granites are quarried for monumental uses.

Near Lakeside, San Diego County, a fine-grained, light gray granite known as "Silver Gray" is quarried for monumental and other ornamental work. Granite is also produced in this county at El Cajon, Escondido, Santee, and near Temecula, the latter locality providing a dark blue rock. Building and monumental granites are obtained at Corona, Riverside, and Wineville, Riverside County, and near Academy, Fresno County. Granite for levees and reclamation work is quarried at times near Andrade, Imperial County. Monumental stone is quarried at Nevada City, Nevada County, and near Chilcoot, Plumas County, that from the latter place being sold as "Light Pearl." A quarry at Folsom, Sacramento County, provides stone for the construction of prison buildings.

Maryland.—Block granite produced in Maryland in 1928 was valued at $430,946, or 1.7 per cent of the total production value for the United States. About 87 per cent in value was used for structural purposes,

chiefly as rough building stone, about 10 per cent as rubble, and the remainder as curbing and paving stones. The building-granite industry has grown from a value of less than $50,000 in 1919 to nearly $400,000 in 1928. Production in 1929 was valued at $229,080; in 1936, $44,955; and in 1937, $190,546.

The Maryland granites are confined to a belt running north-east from the Potomac River to the Pennsylvania border, the southern end of the belt extending from Washington, D. C., to a point near Seneca. It occupies a position on the eastern slope of the Piedmont Plateau bounded on the east by the gravels and clays of the Coastal Plain and on the west by the less crystalline rocks of the western Piedmont slopes. Within this zone granite is prominently developed in about 15 areas, and in at least 5, quarries of considerable importance have been developed. The more important commercial deposits are the granites of Cecil and Baltimore Counties and the granite gneisses of Baltimore and Montgomery Counties.

Granites of Cecil and Baltimore Counties.—At Port Deposit, Cecil County, about 3 miles above Havre de Grace on the Susquehanna River, a light bluish gray biotite granite occurs. A noticeable feature of the rock is a secondary gneissic structure which is due to parallel arrangement of the mica flakes. It is uniform in texture and color, and quarry conditions are favorable. Moderately spaced joints are in three systems, two at about right angles to each other, while the third intersects the major series at about 60°. Quarrying is facilitated by sheeting planes. The granite is used principally for building purposes, such use dating back to 1816 and 1817 when large stones were supplied for abutments of a bridge across the Susquehanna River.

An attractive gray biotite granite, widely used for general building purposes and to some extent for memorial stone, occurs northeast of Woodstock over the county line in Baltimore County. Well-defined sheeting planes dip 10 to 15°, but jointing is somewhat irregular.

Gneisses of Baltimore and Montgomery Counties.—A dark to blue-gray biotite gneiss occurs near Baltimore. Conditions favor quarrying, as sheets dipping 30 to 40° are 4 inches to 5 or 6 feet thick, joints are in two series approximately at right angles and moderately spaced, while the grain (rift) is vertical and nearly parallels one of the jointing systems. The rock breaks out so readily into cubical blocks that scarcely any explosives are necessary. It is used chiefly for rough construction in and about Baltimore.

In southern Montgomery County a similar dark gray granite gneiss is used for bridge, house, chimney, and foundation building. It is so well-supplied with joints and sheeting planes that it is easily quarried. Iron oxide stains in the joints provide attractive nonfading colors for "seam-faced granite." Several bridges on the new Mount Vernon Highway and

many other artistic structures including numerous residences in and near Washington, D. C., are built of stone from these quarries.

Rhode Island.—Granite in the form of dimension stone produced in Rhode Island in 1928 was valued at $413,707, or 1.7 per cent of the value of total production for the United States. Monumental stone dominates the industry, amounting to 92 per cent in value of the total for 1928. About 4.4 per cent was used for building and 3.6 per cent for curbing. Production of building granite was much greater during pre-war years than now. Production in 1929 was valued at $348,173; in 1930, $366,602; in 1936, $292,577; and in 1937, $320,712.

The industry is centered in and near Westerly and Bradford, Washington County. The deposits are unusual, in that they take the form of massive dikes 50 to 150 feet thick intruded into the older granite gneisses, which dip 30 to 45° to the south. The chief joint systems run N.10°–25°E., though various other systems have been noted. The rift is horizontal or slightly inclined, and the grain is vertical or nearly so. Three main types of commercial granite occur: "Westerly Pink," sometimes called "Westerly Statuary," a pinkish or buff biotite granite (quartz monzonite) of very fine uniform texture; "Blue Westerly," a bluish gray biotite granite of fine, even-grained texture; and "Red Westerly," a reddish gray granite speckled with black, having an even-grained medium, inclining to coarse, texture. "Westerly Pink" and "Blue Westerly," the fine-grained rocks, are used for monuments, and the coarser-grained red rocks for construction. The pink and blue varieties take a high polish and are attractive in color and texture. They are well-known to the monument trade and have been widely used for many years.

Connecticut.—The value of block granite produced in Connecticut in 1928 was $396,344, or 1.6 per cent of the value of production for the entire country. About 61 per cent was devoted to monumental purposes, 23 to building, and 16 to curbing. Production in 1929 was valued at $710,739; in 1930, $496,124; in 1936, $144,108; and in 1937, $233,059.

Granites, granite gneisses, and related rocks occur in many parts of the State, and their geologic relations are complex. Production of dimension stone is confined chiefly to four counties—Hartford, New Haven, New London, and Windham.

Hartford County.—Near Glastonbury a biotite granite gneiss occurs in nearly horizontal sheets up to 3 feet thick. The rift follows the foliation, dipping about 10° in a direction N.50°W. The rock is well-adapted for rough construction and curbing, and the products are sold chiefly in Hartford.

New Haven County.—Near Ansonia a blue-gray muscovite-biotite granite gneiss is quarried for rough construction and curbing. The most important quarries of the county are near Branford and Stony Creek. The "Branford Red" rock is a reddish gray biotite granite gneiss of

medium to coarse, irregular texture. It is an attractive building stone and has been used widely in many important structures; it is also employed to a limited extent for monuments and curbing. "Branford Pink" is another type produced in this district. "Stony Creek Red" is a reddish gray coarse-grained gneissoid granite used for buildings, monuments, and mausoleums.

New London County.—The most important granite quarries of Connecticut are in southern New London County near East Lyme, Groton, Millstone, Niantic, and Waterford. At East Lyme and Niantic an even-grained, pinkish gray granite provides an attractive monumental stone sold under the name "Golden-Pink Niantic." Like the Westerly (R. I.) granite it occurs as a dike, in this instance about 40 feet thick intruded into a gneiss. At Groton a fine-grained, greenish gray granite is quarried for monuments. Production is most active in the Millstone and Waterford districts. "Millstone" granite which is available to both rail and water transportation is a fine-grained, dark gray stone used for monuments, paving stones, curbing, and to a limited extent building stone. At Waterford the rock is buff-gray, but the hammered face is light gray. It takes a fine polish and is marketed as "Connecticut White," being used as an architectural stone, for monuments, and for paving stones. Like the other granites of this district it occurs in dikelike masses.

Windham County.—A biotite granite gneiss is quarried near Oneco in southern Windham County near the Rhode Island line. "Oneco" is an attractive fine-grained, dark bluish gray stone used for building purposes and for curbing.

Pennsylvania.—Granite dimension-stone production in Pennsylvania in 1929 was valued at about $383,500. About 70 per cent of this amount was building stone; 22, monumental; 6, rubble; and 2, paving stones. The 1928 figures were not representative. Production in 1930 was valued at $359,045; in 1936, $263,287; and in 1937, $268,859. Pennsylvania is unique in that large quantities of granite gneiss are quarried for house construction and other local uses, particularly in the Philadelphia district. Figures as reported are probably low because a great number of small operators do not submit reports.

Monumental Granites.—Diabase and gabbro, classed as "black granites" are produced in small quantities in Berks County, and in larger quantities in Bucks and Chester Counties. Black granite has been quarried in Bucks County near California—"French Creek Black" at Roedey and "Blue and Dark Pearl" at Shelly—but recent production has been chiefly from the Coopersburg district. A jet-black stone showing splendid contrast between polished and tooled surfaces is marketed as "Bonnie Brook Black Granite." Similar stone is produced near Saint Peters, Chester County.

Building Granites.—Practically all the rock classed as building granite is an attractive, durable, dark granite gneiss which occurs abundantly in many parts of Philadelphia and Delaware Counties and to some extent in Montgomery, Chester, and Bucks Counties. None of the quarries are large, though some provide considerable tonnage for use in and about Philadelphia. In many places stone excavated in digging cellars is used for foundation work and even for buildings. The extensive use of these gneissic rocks has had a marked influence on the architecture of the Philadelphia district. Some of the buildings have withstood weathering influences remarkably well for more than 140 years.

South Dakota.—The value of block granite produced in South Dakota in 1928 was $220,898, or 0.9 per cent of the value of total production for the United States. Practically the entire amount is classed as monumental stone. Before 1925 South Dakota was a producer of granite in a very small way, but since that date the industry has grown rapidly. Production in 1929 was valued at $280,245; in 1930, $397,047; in 1936, $406,115; and in 1937, $547,334.

Production is confined almost exclusively to Grant County, where about five companies operate. The deposits are part of the granite belt of the upper Minnesota River Valley, which is described in the section on Minnesota, and the rock quarried near Milbank and Bigstone City is similar to that near Ortonville and Odessa, Minn. It is sold under the trade names "Hunter's Mahogany" and "South Dakota Mahogany." Some of the stone is shipped in rough blocks to finishing plants in Ortonville, Minn.

Rushmore Mountain, in the Black Hills of South Dakota, has been a center of interest since 1929, when Congress authorized funds for carving a gigantic memorial on the granite mountain face. A brief story of Our Country written in part though not completed by Calvin Coolidge will be carved deeply upon an entablature 80 feet wide and 120 feet high; accompanying this history, carved in colossal proportions, will appear the figures of Washington, Jefferson, Lincoln, and Theodore Roosevelt. A related project at Stone Mountain, Ga. is described under the granites of Georgia.

Texas.—Block-granite production in Texas in 1928 was valued at $191,084, or 0.8 per cent of the value of total production for the United States. Production in 1929 was valued at $165,807; in 1930, $220,189; in 1936, $66,708; and in 1937, $52,361. The industry is confined chiefly to Llano, Burnet, and Gillespie Counties in the west-central part of the State. Llano, the most productive county, is the source of a fine- to medium-grained, light to dark gray granite which is used almost entirely for monuments. A coarse-grained red granite quarried at Granite Mountain near Marble Falls, Burnet County, is well-adapted for building

purposes and was used for the construction of the Texas State Capitol at Austin. It is also used for jetties, breakwaters, and other wave-resistant structures and employed to a limited extent for monuments. Near Fredericksburg, Gillespie County, an attractive red monumental stone is quarried. Most of the products are sold within the State, though some are shipped as far as New York City.

Other Producing States.—The 16 States discussed in the preceding pages provide nearly 96 per cent of the production of granite as dimension stone in the United States. Most of the remaining 4 per cent is reported from six States—South Carolina, Colorado, Oklahoma, Delaware, Montana, and Washington. In production value some of these States exceed members of the minor group of eight States previously described, but the number of producers is so small that production statistics have been withheld to avoid revealing individual figures.

An attractive fine-grained, gray biotite granite quarried at Rion, Fairfield County, S. C., is sold widely for monuments under the trade name "Winnsboro Blue."

Colorado also produces attractive monumental granites valued at more than $200,000 a year. Chief production is from Salida, Chaffee County, where a fine-grained, dark blue-gray quartz diorite is sold under the names "Salida Blue" and "Salida Dark Gray." Monumental stone is also obtained in Fremont County.

Oklahoma and Montana are producers of monumental granite, and Delaware supplies a rough construction stone similar to that produced in eastern Pennsylvania.

An attractive dark red granite or syenite is quarried near Graniteville, Iron County, Mo. The products are monumental stone and paving blocks, the former being marketed widely as "Missouri Red"

A light gray granite has been quarried quite extensively in Little Cottonwood Canyon about 20 miles from Salt Lake City, Utah, and used for building purposes in that city.

Block-granite production in the State of Washington ranges from $10,000 to $50,000 a year in value. The most important production center is Medical Lake, Spokane County, where a fine- to medium-grained, light gray granite is quarried, chiefly for the manufacture of memorial stones. A small production of building and monumental granite is reported at times from Index, Snohomish County.

Volcanic tuffs and related rocks are used to some extent for building in Idaho, Arizona, New Mexico, Nevada, and California. Those in Idaho have been described by Behre.[21] The Arizona State Capitol and several buildings of the University of Arizona are built of tuff. An

[21] Behre, C. H., Jr., Tertiary Volcanic Tuffs and Sandstones Used as Building Stones in the Upper Salmon River Valley, Idaho. Contributions to Economic Geology, pt. 1, 1929, U. S. Geol. Survey Bull. 811-E, pp. 237–248.

ash-gray tuff weighing only 65 pounds a cubic foot occurs near Pioche, Nev. Nails may be driven into it almost as easily as into wood. Porous tuff and pumice are cut into blocks and used as natural light-weight building materials.

QUARRY METHODS AND EQUIPMENT

Choice of Location.—Granites occur widely in many States. Single masses, as indicated by numerous related outcrops, may extend over thousands of square miles. However, relatively few of these occurrences have the qualities, locations, or working conditions requisite for adaptability to industrial uses. Nature has been the fabricator of the rocks, and man is powerless to change the inherent qualities of native beds; therefore, selection of an area of rock with qualities suitable for industrial uses is of paramount importance. First, outcrops should be examined carefully. If a mantle of overburden hides the surface of the rock it may be trenched, but adequate study can be made only when it is removed. Stripping may be done by any method described in a previous chapter. Some quarrymen recommend examination of rock during or immediately after a rain, because hair lines, streaks, and knots are recognized more easily on a wet than on a dry surface. Areas chosen for quarrying usually include masses of rock of uniform texture, attractive color, and relative freedom from irregular or closely spaced seams and from dikes, knots, or hair lines. Requirements for monumental and polished architectural stones, are most rigid; but more liberal variations in color and texture are permissible for building, paving, and curbing granite, while rock of quite uneven texture and color, such as the gneisses and schists, may be used for rubble and other rough-faced types of building stone.

Plan of Quarrying.—The position and direction of quarry walls usually are governed by the joint systems, because an open joint usually constitutes a "heading" or quarry wall. Quarrying conditions are most favorable where two systems of vertical joint seams are at right angles to each other, as this permits easy development of a rectangular quarry opening and the production of rectangular blocks. Many granite deposits occur as domes rising above the general level, permitting wide and shallow quarries, with easy access. This type of quarry has many advantages, particularly in New England because the sheeting planes, which assist greatly in separation of blocks, are almost invariably much closer together near the surface than at depth. A typical bench or shelf quarry is shown in figure 23. In some places quarries are sunk to depths of 200 feet or more. Deep quarrying may be occasioned by restricted property lines or by improvement in the quality of the rock at depth. The plan of quarrying may be influenced by dikes or other structures.

Quarry Operations. *Drilling.*—Drilling greatly exceeds every other quarry operation in importance, for granite is so hard that no tools but

drills can cut it in a quarry. Hand-sledged drills date back many years but have been gradually superseded by steam-driven reciprocating drills. The latter types, both steam- and air-driven, are still in use, but compressed-air hammer drills are most common in modern granite quarries. Drilling equipment has been improved greatly during recent years. The increasing rate of drilling is due in part to the use of better machines and in some measure to the employment of highly efficient mechanical drill sharpeners. A modern quarry blacksmith shop is a marvel of speed and accuracy in reconditioning drill bits.

The principal constituents of granite are, with the exception of mica, as hard as, or harder than, steel, hence drill bits dull rapidly and lose their

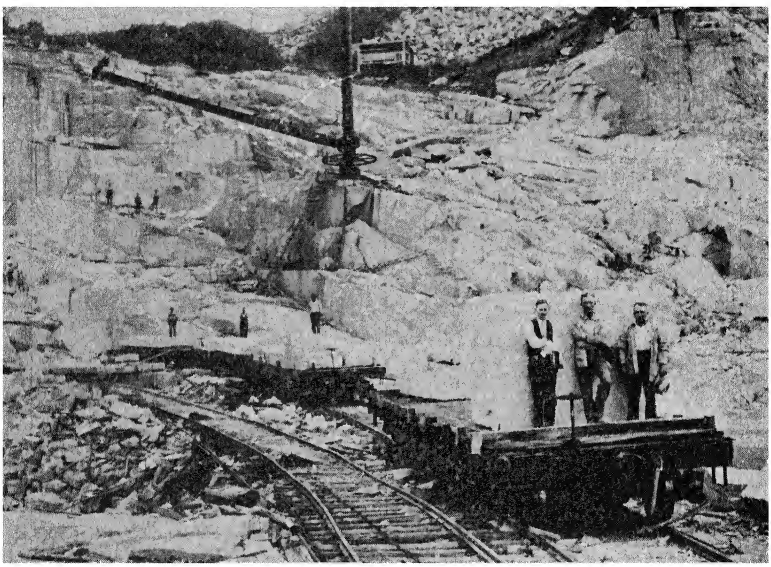

FIG. 23.—A typical bench or shelf granite quarry in Vermont with convenient railroad transportation.

gage as a result of abrasion of the outer edges. Therefore, after depths of 2 to 4 feet are attained steel is changed, and with each change a bit $\frac{1}{8}$ to $\frac{1}{16}$ inch smaller is used. In general practice, many holes are drilled 12 to 15 feet deep, and depths of 20 to 30 feet are not uncommon. Starting bits are $1\frac{3}{4}$ to $2\frac{3}{4}$ inches in diameter on the cutting end; the larger size is used for deep drilling.

A great advance in drilling practice was attained with the invention of hollow steel. Exhaust air passes down the hole in the center of the bit and blows rock dust from the cutting edges, promoting effective work. Air-operated devices for feeding the bit downward and for lifting the drill head when steel is changed have reduced greatly the physical labor and increased the speed of drilling.

The drilling rate in granite is slower than in most rocks. At Westerly, R. I., thirty 4-foot holes a day is a fair average rate attained with a tripod reciprocating drill using a 1¾- to 2-inch bit. At Barre, Vt. each bar-drill machine averages 100 to 120 linear feet a day for moderately deep drilling, using a 2¾-inch bit as a starter. Exceptional rates of 175 to 200 feet a day have been attained.

A bar drill is a type of equipment which has long been used but recently has been greatly improved. A horizontal bar 12 to 14 feet long is supported by a pair of steel legs at each end. A heavy hammer drill is mounted on the bar and may be moved quickly to any desired position by means of a pinion working in a rack of cogs extending the full length of the bar. The chief function of this drill is to make rows of closely spaced holes exactly in line and in one plane. A four-point hollow steel bit generally is used. Reciprocating drills mounted on tripods are sometimes used for deep drilling, and are occasionally used on bars.

For shallower holes used in plug-and-feather wedging hammer drills held in the hands usually are employed. The ordinary hammer drill, with a six-point bit and automatic rotating device, is used for "foot holes," a name applied in Vermont to holes 1 or 2 feet deep. Hand-held hammer drills are also used for putting down deep single holes or small groups of holes for blasting. These are much lighter in weight than the machines used on bars, and the drilling rate is somewhat slower, averaging 75 to 100 feet a day.

For holes 4 to 6 inches deep and about ¾ inch in diameter a smaller type, known as a "plug drill," is used. Valve action depends upon pressure of the bit, therefore it operates only when the steel is pressed firmly against the rock. The bit, usually of the chisel-point type, is rotated by a hand wrench or automatically as a result of special sharpening.

Reaming.—A reamer is a flanged tool driven into a drill hole to cut grooves on opposite sides. Reaming greatly assists blasting, especially by the Knox method, mentioned in its application to granite quarrying under Blasting. It may also be employed to assist straight splitting when the wedging method is followed.

Broaching.—Broaching is the process of cutting out webs or "cores," as they are sometimes called, between closely spaced drill holes to make a continuous channel. A broaching tool resembles a flattened drill bar. The cutting end is about 3 or 3½ inches wide and 1½ inches thick, sometimes with transverse ridges on the face. It may be used in a drill head. After a row of holes has been completed the full length of the bar broaching tools are substituted for drills, and all cores or webs between holes are cut away. Broaching is usually slow and with increasing depth becomes even more laborious, for as drill holes become smaller the cores or webs become correspondingly wider.

Blasting.—Blasting is commonly employed to obtain large fractures, but great care must be exercised in the use of explosives to avoid shattering the rock. Dynamite is used for breaking up waste rock, but in good granite the slower-acting black blasting powder is invariably employed. A charge is the minimum amount that will make a single fracture. If too much explosive is used incipient fractures may be developed in quarry blocks. Such fractures, which may be so small as to be unobservable until the rock is polished, are doubly detrimental, as they not only cause waste but result in condemnation of a block after much time and labor have been spent in shaping and finishing it.

Straight, even breaks, with a minimum number of drill holes, may be made by employing the Knox system. This involves the use of a reamer which when driven into the hole cuts grooves about one-fourth inch deep on opposite sides. Care is taken to cut the grooves exactly in line with the desired direction of splitting. This system, already described in detail in the chapter on sandstone, also involves the use of an air space above the powder charge, which increases the effectiveness of the explosive force. A uniform, straight fracture with an area greater than 100 square feet sometimes is made by blasting in a single reamed drill hole. Occasionally several parallel holes are made, or three or four may be drilled in a fanlike arrangement.

Wedging.—Channeling and blasting have their proper places in quarry work; but most fractures, especially those of smaller area, are made by wedging. Plug-and-feather wedging has been described. Small plugs and feathers are used in ¾-inch "plug" holes 4 or 5 inches deep and 6 to 18 inches apart. They are sledged lightly in turn back and forth along the line until a fracture is made. Plug-hole wedging is effective in rift and grain directions, even for large breaks. A few years ago the writer observed in a Georgia quarry a single mass of granite 8 feet thick, 7 feet 8 inches wide, and 375 feet long separated by the plug-and-feather method with holes 5 inches apart and only 5 inches deep. If a break is to parallel the hard way of the rock "foot holes" 1 to 1½ feet deep are drilled 1½ to 4 feet apart, with plug holes between them. The longer plugs and feathers used in the deeper holes are known as "foot wedges." The straightest fractures are obtained when made in the center of a rock mass. If a small piece is to be wedged from the side of a larger block the fracture tends to run toward the lighter side. In making large fractures the wedging process is not hurried. Plugs are driven firmly, and then a little time is allowed for the fracture to start before sledging is resumed.

Hoisting.—Most granite quarries are equipped with derricks having steam or electric hoists. In wide quarries where booms can not reach all parts, stone blocks or boxes of waste may be handled beyond the boom radius by attaching a line from some other near-by derrick, the two working in conjunction.

In New England wooden derricks with masts and booms of Oregon pine are generally used. They are large and powerful, can handle blocks weighing 40 or 50 tons, and in exceptional instances attain a capacity of 80 tons. At some Maine quarries the original timber for the boom is sawed lengthwise in the center, blocks of timber are placed between the two parts at various points, and the halves are bolted together through the blocks. Sheaves are mounted in the space between the halves. Such "split" booms are less liable to warp and twist than single timbers, and therefore the sheaves run true and do not wear the cable. A 50-ton-capacity derrick may have a mast 100 feet high and a boom 95 feet long. In Minnesota angle-steel derricks generally have replaced wooden derricks. Several quarries are equipped with overhead cableways, but their lifting capacity is usually very much lower than that of derricks.

Quarry Methods. *Influence of Physical Properties and Rock Structures.*—Channeling-machine methods used in the softer rocks (limestones, sandstones, slates, and marbles) do not apply to granite, which is an exceptionally hard rock; hence, as previously explained, drilling is substituted therefor. As artificial cuts are costly, full advantage is taken of open seams or "headers" for quarry or bench walls. As far as possible, all block separations parallel the directions of easiest splitting—the rift and grain. It is a fortunate circumstance that in many granite districts the rift parallels one of the major jointing systems, for in the natural development of a quarry, successive partings thus parallel both rift and joints.

Sheeting planes or "bottom joints" greatly assist quarrying. In fact, vertical breaks can not be made successfully until the mass is free at the quarry floor. If open sheeting planes are provided in nature, successive masses may be removed with ease. If such bottom joints are far apart or absent artificial sheeting planes must be made, possibly by drilling a series of horizontal holes, sometimes termed "lift holes," and making a fracture with wedges or by the use of explosives. The cost of quarrying is usually relatively high in deposits where floor breaks must be forced by wedging or blasting.

Many deposits occur in characteristic domelike form, and sheeting planes usually are arched to parallel in a general way the surface contour of the rock. This attitude of sheeting planes is an advantage in quarrying, for as an opening is made in the side of the dome the quarry floor slopes away from the working face, providing automatic drainage and greatly facilitating the movement of heavy blocks of stone. Sheets are sometimes relatively thick, and joints are spaced close together. Openings in deposits having such a preponderance of joints are sometimes termed "block quarries," because they provide massive cubical blocks. Quarries in the St. Cloud district, Minnesota, are of this type. Con-

trasted with them are the typical quarries of New England, where sheets are thin and joints widely spaced. In such openings the quarry face rises in a series of low steps. The layers are usually thin near the outcrop, gradually thickening as the quarry face is worked back into the dome. As a rule, they also gradually thicken with depth. Openings in rock of this type are sometimes known as "sheet quarries." Figure 24 shows the typical New England sheet structure. Exceptionally, sheeting planes are far apart in New England quarries, for example, in some at Barre, Vt.

Channeling.—"Channeling" in granite quarrying has quite a different meaning than when employed in limestone or sandstone. In the latter

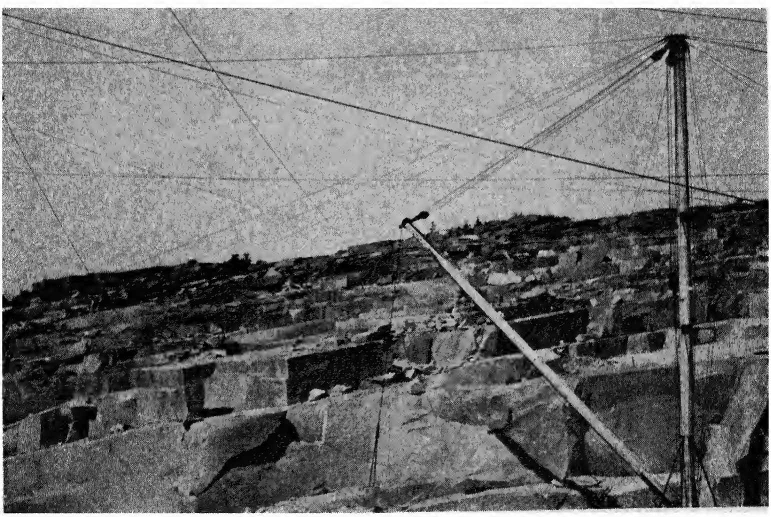

FIG. 24.—A typical New England granite quarry illustrating sheet structure; Stonington, Me.

rocks it is the process of making a cut with a channeling machine, whereas in granite it refers to the drilling of a closely spaced row of holes and broaching or cutting out the narrow webs or cores between. Cuts thus obtained are similar to those resulting from the operation of channeling machines in the softer rocks. This method is employed in many quarries in preference to blasting because, although slow and more costly, it gives a straight surface and does not cause shattering. Its advantages are most apparent in making cuts in the hard way. Channeled rock surfaces are shown at the top and upper right corner of figure 25.

Primary Cuts.—The first step in quarrying is to separate the larger masses from the solid ledge. To obtain space for movement of blocks at the quarry wall it may be necessary to cut a channel. Wall channeling usually is done in the direction of the head grain, or hard way. Channeling tight ends is sometimes difficult because the rock in some deposits,

especially those in which few joints occur, is under compression, and when the drill holes provide a means of relief the rock expands: thus pressure may partly close the drill holes. It is claimed that at Stone Mountain, Ga., a mass 60 feet long will expand 2 inches.

The most difficult step in opening up a new bench on a quarry floor is to obtain a free face from which to work. To give necessary working space a mass of rock 3 to 5 feet wide, and the depth of the bench, must be removed. Different methods are employed to make such a trench or

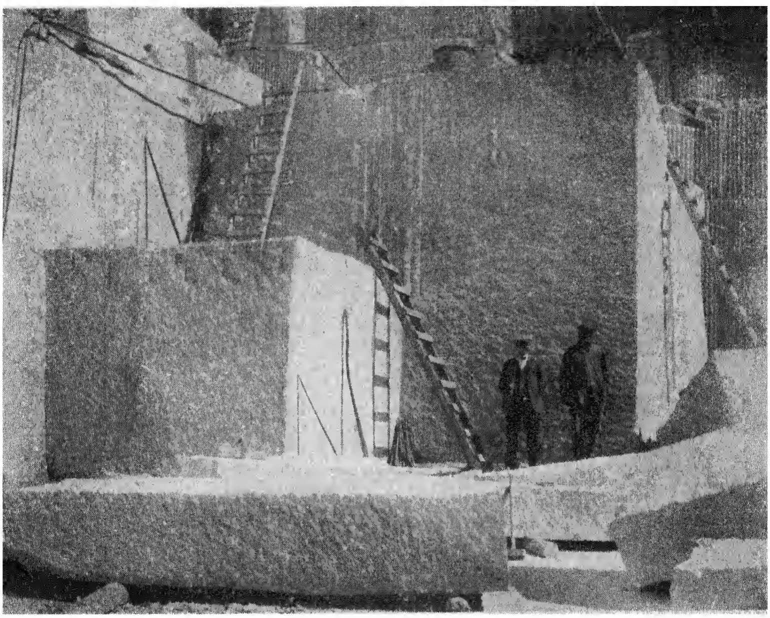

Fig. 25.—Granite quarry at Barre, Vt., in which various methods of drilling are illustrated. (*Courtesy of E. L. Smith & Co.*)

keyway. If the mass is flanked on either side by an open seam the intervening rock may be removed by drilling and blasting. If open seams can not be utilized holes may be drilled in two parallel rows 3 to 5 feet apart, and the intervening rock shattered with dynamite may be removed as waste. Another method is to make two channel cuts 10 to 15 feet apart by the process described in a preceding paragraph and to remove the mass of rock between them. This method is less wasteful than blasting, as the rock between channel cuts may be removed as quarry blocks and utilized, at least in part.

A unique method is employed in a large quarry at West Chelmsford, Mass. A drum core drill, using steel shot as abrasive, cuts a series of holes along the center and across the ends of the quarry. Webs 8 to 10 inches wide are left between the holes to protect the drill from rock

movement occasioned by pressure. The webs are removed later with light powder blasts, and a channel is thus formed. The circular cores, 52 inches in diameter, are cleverly utilized by quartering them for the manufacture of corner curbstones. They are more accurate in shape and have smoother surfaces than rough-hewn curbstones.

Separation of Larger Masses.—When an open bench has been secured by any of the methods previously described, free faces being thus provided, the next step is to separate large masses from the solid ledge. In "block quarries" or "boulder quarries," as they are called in Vermont, where sheeting planes are widely spaced, primary separations may set free blocks weighing thousands of tons. If the bench approaches 20 or more feet in height the larger fractures are made by blasting. "Lewis" holes 2½ to 3 inches in diameter are drilled several feet apart and from one half to almost the full depth of the bench, at the bottom of which is a sheeting plane. A fracture is made by discharging black blasting powder in the holes according to the method described under blasting. Usually this break is on the rift or grain. In rock which splits easily three holes in fan-like arrangement may suffice. A series of deep holes in which explosives have been discharged are shown in the center of figure 25.

When a vertical break is thus made the mass of rock may still be too heavy for wedging. If so, horizontal holes are drilled at a point about halfway down the bench face, and light charges of powder are used to fracture the rock along the plane of horizontal rift or grain. Some quarrymen do not favor channeling beyond a depth of 10 or 12 feet. If sheeting planes are 20 or more feet apart the rock is removed in two "lifts," the bottom of the first being opened with powder charges in horizontal holes.

In "sheet quarries" where sheeting planes are close together blasting may be required only for making primary trenches, and all subsequent breaks are made by wedging. In such deposits quarrying usually is simpler and less costly than in those where sheeting planes are widely spaced.

Forcing Sheeting Planes with Compressed Air.—An ingenious method of making artificial bottom joints is employed in North Carolina and Georgia. Certain deposits, notably at Lithonia, Ga., and Mount Airy, N. C., consist of low, massive domes that are unique in that one may walk over the bare surface of the rock for hundreds of feet without finding any indication of a joint. Sheeting planes are likewise far apart or entirely absent. To remove the larger masses of stone it is first necessary to make artificial floor breaks.

At one Lithonia quarry as observed by the writer, two holes of about 3-inch diameter are drilled close together to a depth of about 8 feet. Two men may work at these holes for weeks or even months. A very small charge of black blasting powder, not more than a spoonful, is

placed in each and tamped with clay, and the charges are fired simultaneously with an electric battery. The force of the explosion starts a small fracture running outward from the bottoms of the holes. This process is repeated time after time, with gradual increase in the size of charges, and the fracture extends slowly. A quarryman skilled in this type of work can readily judge the extent of the fracture, for when standing on the surface of the rock some distance from the drill holes he can determine from the nature of the jar when charges are fired, whether or not the fracture has reached the point over which he is standing. Any attempt to hasten the operation by increasing the charges too greatly would be disastrous, as it would force a vertical or inclined fracture and render continuance of the process impossible. Solar heat assists the process so materially that it is deemed advisable to suspend operations in winter.

The blasting process is continued until the outward boundary of the horizontal fracture forms a circle with a 60- to 80-foot radius. An iron pipe is then placed in each drill hole and the space between the pipe and the rock filled with jute or sand bags and melted sulphur, making a strong, airtight joint. Connection is then made with the air line, and compressed air at a pressure of about 100 pounds per square inch is injected through the pipes to the fracture. The effect is remarkable, for the air pressure immediately widens and extends the fracture until it emerges at the surface on the flank of the dome or at some distant line on the quarry floor. A sheeting plane thus formed may cover an area of 1 or 2 acres and provide a mass of rock large enough for an entire season's operation. The above process is modified somewhat by different operators.

Employment of compressed air to break rock in this manner does not bear promise of being accepted as general quarry practice, because its application is greatly restricted by quarry conditions. Most commercial deposits are intersected by joint systems, and obviously open joints would provide a means of escape for explosive gases generated during the blasting process, rendering it ineffective and also permitting escape of the compressed air used in the final operation. Thus, the process can be employed only in those unique occurrences where joints are very far apart.

Subdivision of Blocks.—After large masses are separated from a solid ledge the next step is to subdivide them into blocks of the approximate sizes and shapes desired for finished products or into sizes convenient for removal from the quarry. Quarrymen follow the direction of rift and grain in making secondary and following fractures, just as they do in primary breaks. The wedging method is used almost universally. Wedging in plug holes may suffice to give a straight fracture in directions of rift and grain. For subdivision of large blocks the line of plugs may be

continued down the ends, as well as along the top, as shown in figure 26. Wedging from both ends and top tends to insure a straight split. For breaks on the hard way "foot holes" may be put down to depths of 12 to 18 inches and 2 or more feet apart, with several shallow plug holes between. "Foot wedges" are driven in the foot holes, and small wedges in the plug holes. Foot holes with four intervening plug holes are shown at the left center of figure 25, page 149. Holes sometimes are reamed for making splits on the head grain.

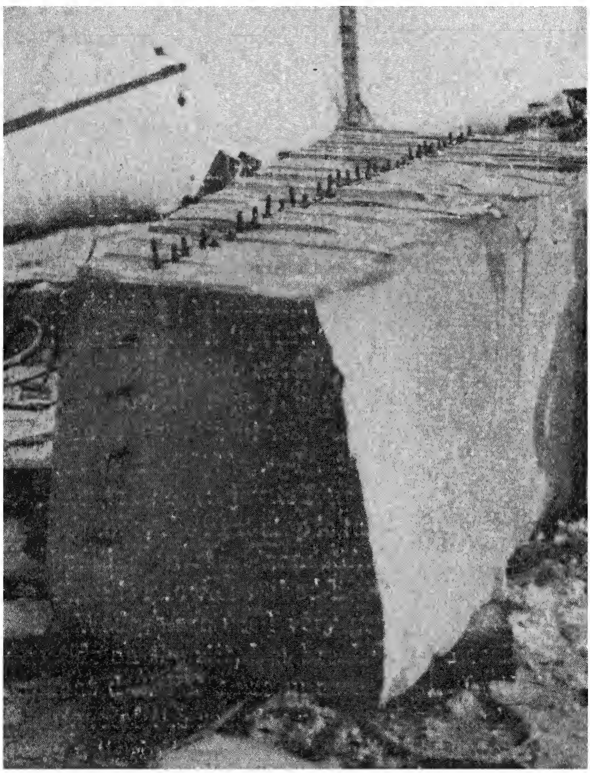

FIG. 26.—Subdivision of a block of granite in a Westerly, R. I., quarry by wedging on top and end. (*Photo by the author.*)

The above methods apply where the weight is approximately balanced, that is, where the line of drill holes is near the center of the mass. Frequently there is a demand for a relatively thin mass of rock, possibly not more than 2 or 3 feet thick but of wide area, such as for a platform or the roof of a mausoleum. At Barre, Vt., separating such a mass is known as "deep holing." Holes about 6 inches apart are drilled in line to almost the full depth of the bench, and a fracture is made by driving "foot-hole" wedges therein; or, sometimes long wedges are used. If shallow holes

were employed the fracture would curve and run out toward the thinner mass, but deep ones carry the fracture straight through. The same rule applies in the subdivision of smaller blocks. In figure 27 a thin slab that has been separated by deep-hole wedging is shown suspended in midair. It may be observed that the block was removed from a point near the

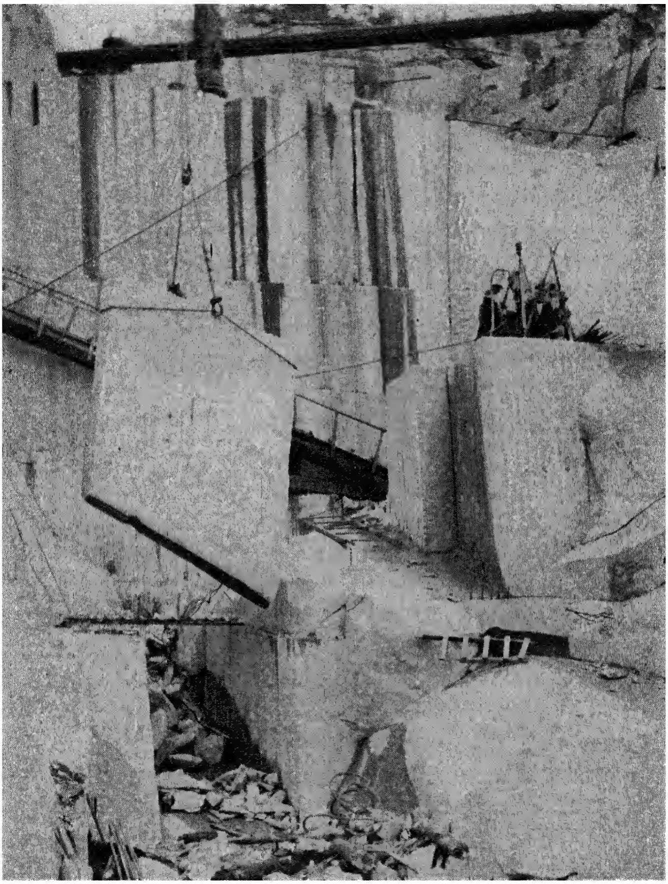

FIG. 27.—A thin slab of granite that has been quarried by deep-hole wedging. (*Courtesy of E. L. Smith & Co.*)

center of the photograph, where plug holes for the final vertical break appear.

An interesting modification of the wedging method is used in Rhode Island. For making a fracture 6 or 7 feet deep holes about 5 feet deep, spaced 1 to 1½ feet apart, are drilled in a row. A steam pipe with numerous right-angled tees is placed parallel with the row of holes, and lengths of hose attached to the branch pipes are inserted to the bottoms of the

holes. Live steam is blown into the holes for 1 to 2 hours, and the expansion caused by the hot steam makes the desired fracture.

Products of monumental granite quarries are of two main types, which may be designated as stock sizes and specials. The former are the standard sizes that satisfy the majority of manufacturers' demands for smaller monuments supplied to the retail trade. As they may be kept in stock quick delivery is assured. Specials are cut to order and may be large or small. Most of them are used in larger, more expensive monuments and mausoleums. They may be made up of 10, 12, or a greater number of stones of different sizes and shapes, cut to size after an order is received. The larger companies usually have a variety of blocks on hand or have benches in the quarry available from which desired sizes may be cut with little delay.

Removal of Stone from Quarry.—Several diverse methods are used for removing granite blocks from a quarry. In wide, shallow quarries, like those at Mount Airy, N. C., and Lithonia, Ga., standard-type tractors, caterpillar tractors, auto trucks, or two-wheeled mule carts are employed. For handling moderate-size blocks a caterpillar derrick crane may be used. Derricks are usually employed for deeper, narrower quarries. Derricks usually are placed in the most convenient positions for loading, and for taking full advantage of a sloping quarry floor if such is present.

As mentioned previously the tendency of sheeting planes or rift to dip downward from the quarry face is of great advantage in removal of blocks. At some quarries, notably at Stone Mountain, Ga., the quarry floor is so steep that blocks slide to the lower edge, where they are lifted by large derricks to standard flat cars for transportation to the mill.

Some New England water-front quarries are so convenient to docks that derricks may place blocks directly on barges. Others have some means of intermediate transportation, and supplementary loading derricks are provided at the docks.

Service Yard.—The aim of the quarryman is to produce either blocks of special sizes cut to order, or standard blocks that may be marketed readily. In the course of quarrying many odd-size or irregular blocks are produced; others may contain imperfections in color or texture in certain places only, necessitating the removal of defective parts. By consulting his order sheet the yard foreman may find that certain special, or smaller standard sizes can be obtained from irregular or defective blocks with minimum waste, and some companies maintain what is known as a "service yard" on the quarry bank where such blocks are subdivided to best advantage.

Quarry Haulage.—Where quarries are on the water front direct loading on barges is possible. Sometimes mills are so close to quarries that little or no intermediate transportation is required, but generally

they are some distance from quarries. As granite usually is quarried in large blocks standard railway cars and locomotives ordinarily are employed for conveyance. Locomotive cranes are very convenient, as they not only haul cars but load and unload blocks. This type of conveyance is used at Westerly, R. I., and in other districts. Where the distance from quarry to mill is short (as at Mount Airy, N. C.) overhead cableways are used both for hoisting blocks from quarries and conveying them to the mills. Wagon and truck haulage is used to a limited extent.

Disposal of Waste.—Waste at granite quarries results from many and varied causes. Some of it is "sap rock," which consists of weathered or stained material bordering open seams and extending into the rock from a few inches to 2 or more feet. Irregular or closely spaced joints, as well as dikes, streaks, knots, hair lines, or poor color, are common causes of waste. Much rock is lost during manufacture. At Barre, Vt., waste constitutes 80 to 85 per cent of gross production.

Disposal of waste is a difficult problem at many quarries. Some operators have developed a market for part of it. At quite a number of quarries waste is crushed and sold for road stone and concrete aggregate, and large masses are sometimes sold for riprap. Other owners are using the waste from the high-priced products to make cheaper materials, such as ashlar and rubble, but success in such enterprises may be expected only where there is a potential market within reasonable distance.

If a great volume of waste must remain unutilized it usually must be hauled some distance, for if piled close to the excavation it may impede future development. Various means of transportation are employed, and alert quarrymen are constantly trying to simplify operation and thus reduce costs. A common method of conveyance is by cable cars on inclined tracks leading to the top of the waste heap, the tracks being extended as the size of the pile increases. Many cars have automatic trips that dump loads endways or sideways, and the expense of keeping laborers continually at work on the waste heap is thereby avoided. In many places overhead cableways, usually with self-dumping skips, have been successful. Waste often is used to advantage in the neighborhood of quarries and mills to improve harbors, to level low places, to build roads, or to provide ballast for railways.

To most quarrymen elimination of waste is obviously of primary importance; and much attention is being given to thorough understanding of the splitting properties of stone, to efficient sawing and surfacing equipment, and to the most complete utilization of the rock for a variety of products.

Manufacture of Curbing.—The manufacture of curbing commonly is conducted on the quarry floor or in an adjacent yard. Blocks usually are split on the rift and grain to the desired thickness and depth, plugs and feathers being used in small, shallow drill holes. Curb-stones are

of two types—straight and corner; the latter are, of course, curved. Corner curb is the most expensive to make, as more stone is required than for the straight and more labor needed for splitting and dressing. An experienced worker can make a curved split. The part of the stone that appears above the ground or pavement when a curb is placed in position is dressed to a smooth surface, usually with a pneumatic tool, the rougher projections first being removed with a hand tool and hammer; the part that remains underground may have a much rougher surface. Specifications for size and surfacing differ in various cities.

Manufacture of Paving Blocks.—Paving blocks, like curbing, usually are manufactured in or near the quarries. Blocks are subdivided by driving plug-and-feather wedges in shallow drill holes, and the directions of rift and grain are followed carefully because splitting is easier and stone split in the directions of natural cleavage has smooth surfaces that require little trimming.

A "bull wedge" is sometimes used for final subdivision. An air-driven chisel-edged tool cuts a shallow notch parallel to the direction in which the rock is to be split. Two iron "feathers" are placed in the notch, and a short, blunt, steel plug is placed between them. One blow on the plug or "bull wedge" with a sledge will split the block and provide smooth, uniform surfaces. It is claimed that by such means a good break can be made to parallel the hard way. The manufacture of paving blocks is entirely a hand process that has changed little or none in the past 50 years. Stonecutters become very proficient in determining the directions of rift and grain and in the use of tools.

Paving stones are made in a variety of sizes, and there have been attempts to standardize and reduce the number of sizes. Market quotations in New York usually specify 30 blocks a square yard. Specifications for granite paving blocks have been published by the American Society for Testing Materials.[22]

Quarry Costs.—The cost of quarrying granite varies considerably, depending upon quarry conditions, proportion of waste, and methods employed. A detailed study by the United States Tariff Commission, the results of which were published in 1929 (see bibliography at end of chapter), reveals useful data relative to the monumental granite industry. The average direct cost f.o.b. quarry for selected operations in Vermont, Massachusetts, and Pennsylvania was found to be $2.07 a cubic foot of unmanufactured stone.

MILLING METHODS AND EQUIPMENT

Some companies quarry only and sell rough blocks to finishing mills; others own both quarries and mills; while a third group operates mills only, buying rough blocks from quarry companies.

[22] A.S.T.M. Standards 1927, pt. 2, pp. 445–450.

Rough blocks of stone constitute the raw material handled in granite-finishing plants. At first sight it might appear that rock, a commodity so plentiful in nature, is quite ordinary and inexpensive, but the superior quality demanded for monuments and ornamental building stone requires such careful selection and preparation that costs are comparatively high. First-class monumental granite in unfinished blocks is worth $3.50 to $5 a cubic foot. The fabricator, therefore, must utilize his material to best advantage, eliminate waste as much as possible, and exercise skill and judgment in every operation, for mistakes are difficult, if not impossible, to correct.

The granite-finishing plant of 30 or 40 years ago was a shed in which blocks were dressed to desired sizes, shapes, and surface finish almost entirely by hand. Machinery has gradually replaced many hand operations, and mechanization has increased with accelerating speed during the past 10 years. Practically every large granite-cutting plant is now equipped with pneumatic surfacing machines, saws, Carborundum machines, lathes, and polishing machines. However, even in the best-equipped mills, many operations must be classed as hand cutting.

Hand Cutting. *General Processes.*—Hand cutting includes the use of hand tools and hammers, and also of pneumatic tools and surfacing machines that are power-driven but guided over the surface by hand. A rectangular block, as it comes from the quarry, is known as a "pattern." It is raised and supported on timbers at a height convenient for working. The cutter first studies the working drawing of the stone to be cut, observes all dimensions, and measures the pattern to see that it will make a block of the size and shape indicated on the diagram. He then squares the upper surface and removes projections to an approximate level, then the surface is smoothed, first with the coarser tools and then with those that give a finer finish. When one surface is completed the block is turned, and the other surfaces are smoothed in succession, each being squared accurately with those already finished.

A variety of tools is used in cutting granite. Some are the property of the cutters, while others are supplied by the company. They differ in shape and in temper of the steel from those employed for the softer limestones and marbles, though they may have the same names. Cutting granite is in effect a crushing process, as the impact of a hammer on a tool causes hard, brittle minerals to crumble into small fragments or dust. The wooden mallets commonly used in driving tools for dressing softer stones, are ineffective on granite, where sturdier implements are required. The granite cutter's hand hammer is of steel weighing 2½ to 4 pounds, with faces hardened by tempering. The heads of cutting tools are bluntly tapered and slightly rounded on the ends, which are also hardened so that no burr results from continued hammering. Various hand and pneumatic tools used in dressing granite are shown in figure 28. Each

tool has its special function and has been perfected by many years, even centuries in some instances, of practical experience.

Granite cutting may not be so fine an art as metal machining or cabinet making, but angles and dimensions must be reasonably true. In

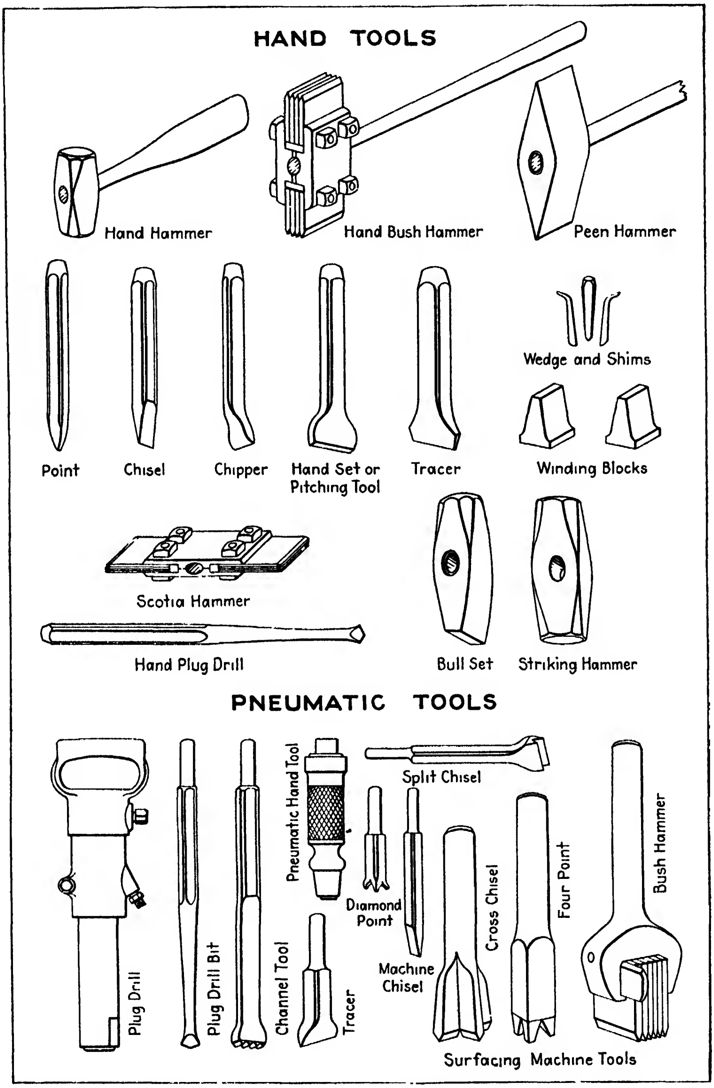

FIG. 28.—Granite cutting tools. (*Courtesy of Federal Board for Vocational Education.*)

fine building and mausoleum work tolerances may not exceed one thirty-second inch and rarely are restricted to one sixty-fourth inch.

Pneumatic tools are guided by hand, but the impact is supplied by compressed air. The tool strikes very rapid blows which require no

effort by the workman; he therefore can direct his entire attention to guiding it in the proper course. Much greater speed is attained by use of such tools than hand hammers.

A "bull sett," one of the most useful tools employed in granite dressing is a heavy, blunt-edged hammer held in position by one man while struck with a sledge by another; it is used for removing irregular ends, which may extend 6 inches or 1 foot beyond required dimensions or for breaking sawed slabs transversely. The removal of unnecessary rock by spalling is known locally as "pitching off." Skill in manipulation, as well as keen understanding of the rift or grain of the rock, is essential when using a bull sett, as a mistake in judgment resulting in a spall breaking beyond the line ruins a block for its intended use.

Operation of Surfacing-machine.—While surfacing-machine work may logically be classed with hand operations it is sufficiently distinct to justify consideration in a separate section. It involves "roughing down" surfaces to a comparatively uniform condition. The first step in manufacture is termed "lining" and involves working the edges of a block to required dimensions, usually with pneumatic chisels. The next step, known as "pointing" or "surfacing," is to dress the faces to edge dimensions with hand tools and hammers or, when surfaces are large and rough, with a surfacing-machine.

The machine consists essentially of a cutting head mounted on a horizontal swinging arm which can be raised or lowered to different working levels. Cutting tools fit into the nose of the cutting head and are driven against the stone by rapid blows of an air-driven piston hammer. An operator guiding the tool over the surface of the stone reproduces the hand-pointing process on a larger scale and about five times as fast. As the cutter travels over the rock it chips off fragments, gradually working down to an even surface. A heavy tool removes the larger projections, followed by various smaller types to finish the surface. Common surfacing-machine tools are illustrated in figure 28.

A surfacer has numerous applications, such as smoothing rock before polishing, smoothing curved or cylindrical surfaces, and recessing panels. It may be employed for rough, heavy moldings and flutings. A four-point tool, which has a square face consisting of four blunt projections, generally is used for recessing and shaping, or for reducing surfaces to an even plane before polishing. If a hammered-surface finish is desired a bush hammer is used in the surfacing-machine. The latter consists of a series of parallel steel plates, and the tools are graded 4, 8, 10, and 12, according to the number of plates, 12 giving the finest surface. Building and mausoleum stone usually has a 10-cut surface, while a 12-cut is preferred for monuments.

A screen of wire netting commonly protects workmen from flying fragments of stone. As much dust is produced dust collectors usually are provided.

Carving.—Carving is a hand operation that demands skill and experience. It is essentially the same process described in some detail under limestone, though granite works much more slowly. A variety of pneumatic tools is used. As a rule, fine-grained granites are best-adapted for carving, though there are notable exceptions. Much of the intricate carving and lettering formerly done entirely by hand is now accomplished by sand blasting.

Sand Blasting.—Sand blasting marks an advance in the art of granite carving comparable in importance to the advent of explosives or of compressed-air drills in rock quarrying. It is more precise, capable of greater detail, and much more rapid than any other carving process.

A polished-rock surface is first coated with a molten rubberlike or gluelike compound, known as "dope," which hardens to a tough, elastic consistency. Lettering and other designs are imprinted on the surface, and with a small sharp tool like a scalpel the coating is removed from all parts that are to be cut below the surface. The cutting of symmetrical designs, rose petals, ivy leaves, and trailing vines requires artistic talent and infinite patience, but carving is accomplished much more expeditiously in the rubbery compound than in solid rock.

Stone thus prepared is placed in an illuminated closed chamber in such a position that the surface to be carved is vertical and faces the operator, who observes it through a window. A nozzle, through which compressed air at a pressure of 80 to 100 pounds per square inch drives a stream of fine sand, or more commonly powdered Carborundum, is held through a curtain which protects the operator from the abrasive dust. The sand blast is directed against the design, and curiously enough the exposed hard granite is quickly cut away while the sand has little or no effect on the soft coating. Certain parts of letters or designs may be cut ½ to 1 inch in depth. The precision and fineness of detail are remarkable. Rose petals may be cut so thin that they are almost transparent. In its higher refinements sand blasting may be done in successive steps. Petals or leaves may be depressed to varying degrees, covered with a protective coating, then outlined by deeper cuts. A screen background produces a series of deep holes in lines resembling a honeycomb. The delicate and exquisite detail attained would be impossible with hand tools, and the time required is reduced to a mere fraction of that which hand carving demands.

Mechanical Equipment.—Machines that have replaced the slow laborious hand work employed 30 or 40 years ago cover three main processes—sawing, smoothing, and polishing. Although much toil has been eliminated in these important processes and production per man has increased enormously since machines were introduced, improvements constantly are being made.

Sawing.—In the early days of granite working drilling, blasting, and wedging were the only known means of subdividing blocks. Granite is difficult to saw, but many years of experiment have developed machines that give effective service. Saws have been used occasionally for a number of years but have been generally accepted only during the past 10 or 15. There are now two well-recognized methods of sawing granite —with gang saws and with circular saws.

Gang saws similar in construction and operation to those described in the chapters on sandstone and limestone are used most widely. The frames of some saws travel back and forth in a straight line; others have the swinging motion so common in limestone sawing. The blades are one-half to five-eighths inch thick, with notches about a foot apart in the lower edge to carry steel-shot abrasive beneath them. The rate of cutting is 4 to 9 inches an hour. Most modern saw beds are equipped with concrete sumps, in which used shot are collected and elevated mechanically to a box above the saws for redistribution. Several blades may be used, and as the frame holding them is carried downward by a worm gear a block may be cut into slabs at one operation.

Circular saws for cutting granite are 5 to 12 feet in diameter and provided with detachable notched-steel teeth. An abundance of water is supplied, and steel shot are fed to the blade continuously. Some saws are provided with automatic shot feed. Granite blocks are mounted end to end on cars and the spaces between filled with plaster of paris to keep the shot in the cut as the saw passes from one block to another. Cars carrying blocks are conveyed slowly beneath the saw, and operation is therefore continuous. Sawed slabs or blocks are removed and empty cars lifted with an overhead crane, carried back to the starting point, and placed on the track again. The rate of travel ranges from 1¼ to as high as 5 inches a minute; therefore the sawing rate in blocks 4 feet thick is 25 to possibly 100 square feet an hour. A disadvantage of the circular saw is its inability to make more than a single cut at once. When slabs are to be sawed on both sides the block is returned to a starting car and carefully aligned for a parallel cut. Both circular and gang saws are used very widely.

An unusual granite-cutting machine, known as the "Chase" saw, consists of a series of nine massive steel blades, about 20 inches wide and ¾ inch thick arranged in tandem, pivoted near the center and swinging back and forth with an edgewise motion actuated by a crank and pitman. Steel shot are used as abrasive. Granite blocks are mounted on a traveling bed and joined with plaster of paris in exactly the same way as for cutting by a circular saw. The machine can saw blocks with a maximum thickness of about 5 feet, and cuts at a rate of about 2 inches a minute in blocks 4 feet thick, or about 40 square feet an hour. Like the circular saw it is limited to single cuts, but its operation is con-

tinuous. In so far as the writer is informed, only one such saw is now in use.

Sawing of granite is costly and therefore employed only in preparing the higher grades of ornamental or structural stone. Though expensive, sawing has certain definite advantages. Thin slabs which could not be shaped profitably in any other way are readily obtained. Furthermore, the most attractive surface on some granites parallels the hard way, and by ordinary methods of splitting with wedges it is difficult to obtain blocks having their larger surfaces parallel to this direction, while sawing may be done as readily in one direction as another.

An important advantage of sawing is conservation of stone. In splitting with wedges irregularities are bound to occur, and much stone is wasted in smoothing surfaces, while a saw removes little more than an inch of material and leaves the surfaces smooth and straight. Such smooth faces are advantageous in following processes, for sawed slabs are smoothed with very little labor before polishing. Sawed blocks of cut stone that have had no surface treatment other than sand blasting are acceptable to many builders and architects.

Finishing the Surface.—A crude form of granite polishing was known to the Egyptians, but the art apparently was lost until rediscovered by granite workers at Aberdeen, Scotland, about 1820. Polished granite is now used widely for monuments and ornamental building purposes; and because of its hardness, crystalline character, variety of color, and transparent grain it has superior beauty and endurance. Sawed slabs, or blocks reduced to uniformity with surfacing machines, are carried through several stages of treatment before a final polish is attained. The successive steps are known in Vermont as "ironing," "emerying," "honing," and "buffing." Although different names may be applied in other States the processes are essentially the same in all granite districts.

IRONING.—Surfaced or sawed blocks are placed in groups of 8 or 10 on a timber bed with their upper surfaces on an even plane. The rectangular group of blocks is surrounded by a wooden box, with the bottom a little lower than the surface of the rock. All cracks in the box and between the blocks are filled with plaster of paris. A worker guides a belt-driven revolving head over the blocks, and steel shot with water coming between the rotating head and the stone gradually wear down the surface. The rotary head, known as a "scroll," is a series of concentric or spiral iron rings or segments of various patterns, some of which are broken or notched. The patterns are designed to keep the abrasive under the scroll as long as possible and to make it cut effectively. For machines guided by hand scrolls may be 3 or 4 feet in diameter. The process of thus wearing down a surface with steel shot is known locally as "ironing." Two beds usually are provided within reach of each machine, and, while stone on one is being smoothed, blocks are being

leveled and set in plaster on the other; thus the machine may be kept in almost constant use.

EMERYING.—The next step, known as "emerying," produces a smoother finish. It requires a lighter scroll and emery or more commonly, Carborundum powder, as abrasive. Three or four grades of abrasive successively finer in grain size are employed, the coarser being washed carefully from the surface before the next is added.

BUFFING.—For the final polishing process, generally known as "buffing," a buffer head is operated in the same way as the scrolls. It consists of a circular disk mounted with numerous folds of paper-mill felt. Putty powder (extremely fine-grained tin oxide) is added, with a moderate supply of water. If more than one surface is to be polished the block is turned and reset in another bed. An experienced worker can completely polish a bed in 1 day. Small surfaces, and designs in other than flat surfaces are polished by hand methods or by small machines which will be described later.

MODIFIED METHODS OF FINISHING SURFACES.—The brief descriptions already given cover processes that have been long used, but certain recent changes and improvements deserve mention. Automatic polishers that require little or no hand work are being used more widely. On some the rotating scroll is driven back and forth over the length of the bed or block, its movement being automatically reversed with a trip set in any desired position.

Another type of automatic polisher travels laterally across a bed mounted directly on a large car. The car carrying the stone moves backward and forward while the polishing wheel travels crosswise, both motions being under control of an operator. Such mechanically operated ironing wheels may weigh 3,000 pounds, and therefore cut very rapidly. Ironing, emerying, and buffing follow in succession by changing the rotating heads and the abrasive. Starting with rough, unsurfaced quarry blocks a final polish may be attained at a rate of about 15 square feet an hour on one machine.

Much surface finishing is now done without setting the blocks in plaster of paris. They are merely placed and leveled on a base block in an enclosed area which collects the splash. A great deal of time is saved thereby. When plaster beds are dispensed with, provision is made for mechanical recovery and return to the surface of used coarser abrasive. A typical mill is equipped with three machines, the first using coarse silicon carbide, the second four successive grades of fine silicon carbide or emery, and the third a buffer head. Automatic polishers are employed, and blocks may be mounted on opposite sides of each machine for alternate and practically continuous operation. It is claimed that such equipment will polish about 350 square feet a day. To attain this

footage, however, sawed slabs only are used, a circumstance which shortens the smoothing time materially, as it eliminates ironing.

SPECIAL SURFACE FINISHING.—Many blocks that can not conveniently be placed beneath a regular buffer are polished with special machines consisting of small buffer heads guided over the surface by hand and driven by small electric motors mounted directly on movable frames. Small, air-driven, portable polishing disks are used for narrow edges. Curved or irregular surfaces are polished by hand.

Carborundum Machines.—Specially designed silicon carbide wheels cut moldings and rabbitts, shape fluted columns, recess panels, and handle similar processes. They must be operated carefully and with an abundance of water. The granite block usually is mounted on a traveling bed that carries it beneath the wheel, which cuts a groove about one-eighth inch deep at each motion. Some wheel mountings may be reversed to groove both the top and bottom of a block. On others the crosshead carrying the arbor unit will swing through an angle of 90° to cut moldings of any desired inclination. A "contour" machine is a special type designed to follow a given pattern. The life of a wheel varies; with fairly constant use one costing $7.50 will last about one day. Carborundum machines cut accurately, and provide a very smooth finish; a single machine accomplishes in a given period very much more than a cutter using hand tools.

Turning Lathes.—Ornamental granite in sound blocks absolutely free from incipient seams is widely used for columns. The shaping, turning, and polishing of columns are a distinct granite-cutting art. The block first is roughed out to an approximately cylindrical form by drilling, wedging, shaping with a bull sett, and dressing down with hand hammer and chisel. Exceptionally, a cylindrical block of granite is cut by means of a rotating drum fed with steel shot.

The rough cylinder is mounted in a lathe in which it rotates slowly. One or more steel disks are mounted on axes inclined about 45° to the axis of the column. The disk is not power-driven but turns freely as its edge comes in contact with the rotating column. As the disk travels slowly lengthwise to the column it chips off projections and gradually works the surface to a uniform cylindrical shape. The column is then ground smooth with steel shot, followed by emery or other abrasive, and polished with putty powder on buffing pads held against it as it rotates.

One mill in Barre, Vt., specializes in cutting columns. Large lathes are provided for turning massive monoliths. Numerous small lathes are employed for small columns, balusters, and spindles, as well as for ornamental urns, vases, and flowerpots, which are used principally in cemeteries. The dimensions and shapes are shown in drawings which for smaller objects are full size. As turning proceeds, diameters are measured with calipers, and contours are fitted to patterns. Square bases and

caps of columns are cut in the lathe with Carborundum wheels, the lathe being locked from turning while each cut is in progress. Silicon carbide wheels also cut grooves in cylindrical objects, the wheel and the stone rotating at the same time. The turned column is placed in another lathe for ironing, emerying, and buffing. An iron plate is fitted to irregular contours, and an abrasive is fed under the plate by hand as the column rotates. For straight surfaces a flat bar is used; for small, curved surfaces a piece of iron pipe is held firmly against the rock and moved back and forth while an abrasive mud is added. Very beautiful polished objects are thus manufactured.

Surface Finishes.—Granite products have various types of surface finish. For certain building and monumental uses a "rock-faced" finish is preferred—that is, a rough broken surface like that obtained when spalls are broken off with a sledge. Edges of rock-faced surfaces usually are outlined with a pneumatic tool.

A "hammered" or "axed" finish is obtained by surfacing with a bush hammer. It shows faint parallel ridges, and the surface is white or very light. A "steeled" surface is obtained by "ironing" with steel shot. It is intermediate in smoothness between hammered and polished, for it shows faintly the color of the rock rather than the uniform white or light gray of the hammered surface; thus, a steeled Barre granite is bluish. A polished surface is the most ornamental, for it brings out the color of each individual surface grain and shows all details of texture. It is also easiest to clean. Polished granite is used widely for monuments and for the lower courses, columns, and other prominent parts of large buildings. A granite that shows a sharp contrast between polished and hammered surfaces is preferred for monuments, because inscriptions stand out prominently.

Arrangement of Mills.—In modern granite mills machines are arranged in logical order, so that blocks travel by the shortest and most convenient route until they arrive at the point of storage or shipment. Overhead traveling cranes handle blocks expeditiously. Small cranes are provided for quick handling of small blocks, while large, powerful, though slower moving cranes, handle masses weighing up to 40 or 50 tons. The general arrangement and operation of cranes are similar to those of limestone-finishing mills described in some detail in a previous chapter. Mills are usually well lighted, heated, and ventilated and are equipped with suction fans for removing granite dust from machines and tools.

Storage and Shipment.—Products of granite mills are sold chiefly to retail monument dealers or to builders and contractors. As large stocks may accumulate, space must be provided for storage, and equipment for handling and loading. Monuments and polished building stones are crated carefully to protect them from damage during handling and

transportation, and usually stored under cover in such positions that they may be readily located and conveniently loaded. Polished and carved surfaces are protected with wrapping paper and sometimes with special waterproof paper under the crating to guard against temporary stains. Building granite ordinarily is stored in the open. Sometimes the stone for an entire structure is cut before any is shipped, which requires careful planning and arrangement so that blocks may be shipped in the order in which they are to be placed. On other contracts rock may be loaded for shipment practically as fast as cut. As granite is a heavy product all unnecessary handling is avoided.

MARKET RANGE

Finished monuments from the mills of Barre, Vt., are the most widely distributed in all granites and are marketed in practically every State. The granites of Quincy, Mass., also are widely distributed. Granite monuments from St. Cloud, Minn., and from Wisconsin are marketed largely in the Middle West, although they are used to some extent in more distant States. The "black granites" of Pennsylvania and New England are sold chiefly in New York City. Building granites produced principally near the Atlantic seacoast of New England, and in Pennsylvania, North Carolina, Georgia, and California are marketed chiefly in the larger cities where they are used for entire structures or for base courses and trim in residences, office buildings, stores, banks, churches, schools, and other public buildings. An important application is in bridge construction. For this use it may be shipped for long distances; for example, Georgia and North Carolina stone has been used in large bridges in Philadelphia and New York.

IMPORTS, EXPORTS, AND TARIFFS

About 60 per cent of the imports of unmanufactured monumental granite is obtained from Sweden. The Swedish granites are chiefly dark varieties, the so-called black granites. Red granite from Finland is second in importance. Imports of monumental base stock and building granite come chiefly from Canada.

Imported manufactured granite consists largely of monument dies with polished surfaces. The chief imports, which come from Germany, consist of dies manufactured from Swedish granite. Finland is second in importance for manufactured as well as for unmanufactured granite. Imported manufactured granite is purchased for the most part by wholesale dealers in Ohio, for sale to retail monument dealers west of the Alleghenies.

According to tariff classification granite exports are combined with exports of a number of other commodities and therefore cannot be shown separately, but the amount is small.

According to the Tariff Act of 1930 granite suitable for use as monumental, paving, or building stone, not specially provided for, hewn, dressed, pointed, pitched, lined or polished, or otherwise manufactured bears a duty of 60 per centum ad valorem; on unmanufactured granite the duty is 25 cents a cubic foot.

PRICES

Building granite is sold principally on lump-sum contracts. When sold on smaller contracts random blocks without cutting or carving are quoted at prices ranging from \$1.40 to \$2.25 a cubic foot at points of consumption. Unmanufactured monumental granite is \$3 to \$4.50 a cubic foot f.o.b. quarry.

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CHAPTER IX

MARBLE

HISTORY

Marble working is an ancient art. Because of its attractive crystalline form marble was one of the first stones to be used for carving and for structural purposes. Biblical references to its use in Solomon's Temple at Jerusalem and the palace of Shushan indicate that it was well-known for building and decoration more than 1,000 years before the Christian era. Parian marble was used by the early Greek sculptors in such famous statues as Venus de Medici, and the Parthenon was built of the renowned Pentelic marble. Carrara, Italy, has long been a center of marble production, as well as of art and architecture. We are, indeed, indebted to the enduring qualities of this stone for preservation of many magnificant and inspiring examples of sculpture and structural design that might otherwise have been lost. Numerous invaluable records inscribed on marble slabs have added to our wealth of ancient history.

DEFINITION

In its geologic sense the term "marble" is applied to rocks consisting of crystallized grains of calcite, dolomite, or a mixture of the two. Marble has the same chemical composition as limestone or dolomite, the chief difference being that the component particles of calcium or magnesium carbonates in limestone are granular and noncrystalline. It is regarded as a metamorphic rock resulting from the recrystallization of limestone.

In its commercial sense, the term has a much wider application. As susceptibility to polish is one of its chief commercial assets, all calcareous rocks capable of taking a polish are classed as marbles. Furthermore, serpentine rocks, if attractive and capable of taking a good polish, are so classed, even though containing little calcium or magnesium carbonates, as they are commercial substitutes for true marbles.

COMPOSITION

Aside from serpentine and other extraordinary varieties, marble consists almost entirely of calcium or magnesium carbonates. A calcite marble may include 95 to almost 100 per cent calcium carbonate. If impurities are disregarded a dolomite marble contains approximately 54 per cent calcium carbonate and 46 per cent magnesium carbonate. Those comprising mixtures of calcite and dolomite may have compositions any-

where between these two extremes. Varying percentages of impurities are present in practically all marbles. The more common impurities are silica (SiO_2), either as free quartz or combined in silicates; iron oxides, such as hematite (Fe_2O_3) and limonite ($2Fe_2O_3.3H_2O$); manganese oxide (MnO); alumina (Al_2O_3), in the form of aluminum silicates; and sulphur, usually as pyrite (FeS_2). Small quantities of organic matter may be present; in some marbles it has been converted into graphite. Impurities occur as common minerals, and their presence gives to colored marble the veins and markings that sometimes adapt it to decorative uses. The more common mineral impurities are quartz or some other form of free silica, such as chert or flint, hematite, limonite, graphite, mica, chlorite, tremolite, wollastonite, diopside, hornblende, tourmaline, and pyrite. In the marbles of southern Ontario, Parks[23] notes the presence of 37 minerals that have been formed by metamorphic processes acting on the impurities of the original limestone. Impurities in their relation to use are discussed more fully on pages 175 to 177.

ORIGIN AND VARIETIES

Marbles may be classed in three groups.

The first group, which includes by far the largest proportion, comprises those resulting from recrystallization of limestone. Most of them are highly crystalline and are usually white, though gray, black, or other markings may be present. A preponderance of the Alabama, Georgia, Vermont, Massachusetts, Connecticut, and southeastern New York marbles are of this type. The original rocks were formed in the sea, mainly as accumulations of the calcareous remains of marine organisms, which were consolidated to form coherent rocks termed "limestone." The origin of limestone is described more fully in the chapter on limestone. Heat and pressure, usually accompanied by extreme deformation of the beds, resulted in the highly crystalline condition most commercial marbles exhibit. Recrystallization as a result of igneous intrusion has been noted. Fossiliferous or subcrystalline marbles have been subjected to less extreme metamorphism, and in many instances the original fossils remain almost intact. They have sufficiently close texture to take a good polish and at the same time show attractive color effects. Water probably has assisted greatly in their recrystallization. In fact, some marbles seem to have been altered from limestones chiefly by circulating water, for they show no evidence of deformation or extreme pressure, nor are they near igneous intrusions.

The second group comprises the onyx marbles. These consist essentially of calcium carbonate and are purely chemical deposits that have not resulted from metamorphism of preexisting limestone beds.

[23] Parks, W. A., Report on the Building and Ornamental Stones of Canada. Canada Dept. of Mines, Mines Branch, vol. 1, no. 100, 1912, p. 307.

Such calcareous chemical deposits are of two types. One, which is regarded as a product of precipitation from hot springs, is termed travertine. As most travertines are porous and can not take a fine polish, they are classed with limestones rather than with marbles. The other type, true onyx marble, usually is regarded as a deposit from cold-water solutions, commonly in limestone caves, hence the name "cave onyx" is sometimes applied to it. Impurities, such as iron and manganese oxides, may be present in varying amounts in successive layers of this marble, and thus beautiful banding may result. This type is commonly known as Mexican onyx because very fine deposits have been found in Mexico. Many onyx marbles are semitranslucent.

The third group includes the verde antiques. The name is applied to marbles of prevailing green color, consisting chiefly of serpentine, a hydrous magnesium silicate. They are highly decorative stones the green color being interspersed at times with streaks or veins of red and white. In no respect are they comparable with true marbles in either composition or origin. Serpentine is in general derived from the alteration of basic igneous rocks, such as the peridotites which are rich in olivine and pyroxene, or from magnesium silicate rocks formed by metamorphism of impure dolomitic limestone. The process is accompanied by hydration, with an addition of 13 to 14 per cent of water. The movement occasioned by the swelling that results probably accounts for most of the unsoundness common to verde antique.

PHYSICAL PROPERTIES

Hardness.—As defined on a previous page, hardness is a measure of the resistance the surface of a substance offers to abrasion. As given in Moh's scale the hardness of calcite is 3 and dolomite 3.5 to 4, whereas window glass is about 6. Marbles are harder than most limestones, for while they may consist of the same mineral—calcite—grains of limestone usually are cemented together less firmly, and hardness of a granular rock is measured by the degree of cohesion between grains rather than by the actual hardness of the mineral. The presence of such impurities as flint or silicate minerals may increase the hardness of a marble very greatly. Hardness of the mass as a whole is an indication of "workability" and is an important property, as the cost of quarrying marbles that are worked slowly by tools is much higher than that of those easily worked. Although the cost of quarrying hard marble may be high, hardness is a desirable property if the material is to be exposed to abrasion.

High resistance to abrasion and uniform hardness are desirable qualities in marbles to be used for sills, steps, or floor tile, all of which are exposed to the friction of feet of pedestrians. In constructing floor patterns of different marbles it is important that they be equally resistant

to abrasion, otherwise the floor eventually will become uneven. This condition may be observed in the Union Station at Washington, D. C., where tiles of relatively pure calcite marble are worn down in places nearly half an inch lower than the smaller squares of harder, colored, siliceous marble.

Specific Gravity and Weight per Cubic Foot.—The specific gravity of a substance is its weight compared with that of an equal volume of water. The specific gravity of calcite is 2.7 and that of dolomite about 2.9. Consequently, dolomite marbles are heavier than calcite marbles. It is found that the actual weight per cubic foot of a block differs more or less from its theoretical weight calculated from the specific gravity of the constituent minerals. A porous rock of given volume will be lighter than an equal volume of similar nonporous material.

The pore space in most marbles is so small that the actual weight does not differ greatly from that calculated from specific gravity. Marbles range from 165 to 180 pounds per cubic foot in actual weight.

Solubility.—The solubility of marble deserves careful consideration if its use for exterior purposes is contemplated, because all stones dissolve slowly or disintegrate when exposed to atmospheric agencies. Usually the rate of solution is extremely slow, but it may be rapid enough under certain conditions to impair the value of stone for building. The rate of solution varies in different marbles, depending on chemical composition, texture, and porosity. Surface waters which contain certain dissolved gases, such as carbon dioxide, dissolve the carbonates to a limited degree. Near large cities various acids from smoke are taken up by rain and increase its power of solution. If a stone is permeable it usually dissolves more rapidly than if impervious. Calcite dissolves more rapidly than dolomite under the same conditions if the texture of each is similar, but the tendency for dolomite to occur with granular texture often reverses the order of their solubility.

Color.—The color of a marble, one of its most important physical properties, is governed by the nature of the constituents. Marbles consisting of pure calcite or dolomite are white, whereas green is the prevailing color of verde antique. Variations from the whiteness of a pure marble are due to admixtures of foreign substances. Such impurities may be distributed uniformly and thus give uniform coloration or they may be present in bands or streaks, giving clouded or otherwise nonuniform colors. Very beautiful banded effects are obtained by sawing veined marbles in certain directions.

The causes of some colors in marbles are easily determined. Black and grayish shades are attributed to carbonaceous matter, which is usually present as fine scales of graphite; red, pink, or reddish brown are due mainly to the presence of manganese oxides or to hematite; yellow-brown, yellow, or cream are caused by minute grains of limonite, a

hydrous oxide of iron. Other colors, such as the bluish tint found in some beds of white marble, are difficult to explain.

Highly colored marbles are usually those that have been brecciated or fractured, subsequent consolidation being accompanied by infiltration of coloring material from surrounding soil and rocks. They are mostly of foreign origin.

For certain purposes, particularly for monuments on which inscriptions are cut, marble which presents a distinct contrast between chiseled and polished surfaces is desirable. A chiseled surface is opaque and somewhat granular and reflects rather than absorbs light; hence it tends to appear white or light-colored, even if the stone is dark. When a face is polished the reflecting surfaces are removed, and light is permitted to enter the crystals and be absorbed, which causes the polished surface to appear relatively dark. The contrast usually is more pronounced in colored and less marked in the white marbles.

Each bed in a deposit exhibits more or less constancy of color; therefore, desirable uniformity in color ordinarily can be maintained by working each bed separately. If the texture or color of marble in a deposit varies, care is taken to quarry in such manner as will tend to produce material that may be closely classified. Some variations in color, though slight, may detract immensely from the market value. Lenses and bands of bluish material may pass irregularly through the white, occasioning excessive waste or necessitating classification in a lower grade.

Colors may be permanent or may change after exposure to sunlight or weather, the more highly colored marbles being most subject to such changes. Severity of climate is an important factor in these changes. Permanence of color is highly desirable. Most high-grade American marbles show very slight color alteration even after long periods. A soiled surface must not, of course, be confused with color changes.

Translucence.—Translucence is a measure of the capacity of marbles for transmitting light. The more translucent varieties, if fine-grained, are best-adapted for novelties or other ornamental purposes. Some marbles look waxy, and this property seems to be related to translucence. The depth to which light will penetrate the best statuary marbles ranges from ½ to 1½ inches. Certain beds in many marble deposits of the United States are exceptionally translucent. The beautiful so-called "transparencies" in the roof of the Lincoln Memorial at Washington, D. C. are translucent slabs of clouded and veined Alabama marble. Certain modes of artificial treatment are known to increase translucence, but usually the effects of such treatment are far less permanent than the material itself and consequently are not to be recommended.

Texture.—Grains of calcite and dolomite that make up a marble mass are crystalline and have a definite cleavage, showing bright reflecting

faces on a broken surface. Usually the cleavages appear about equally prominent in every direction. In some marbles, however, the grains are elongated in one direction by the folding or plication of beds. Most marbles consist of a single mineral, and therefore have a homogeneity that is favorable for resistance to weathering because of uniform expansion and contraction with temperature changes. The texture of a marble thus depends on the form, size, uniformity, and arrangement of its grains, and on the nature and size of grains of accessory minerals.

The size of grain is commonly described as fine, medium, or coarse. Such terms are indefinite and may have quite different meanings, the interpretation depending upon the range of texture experienced by the observer. To place texture upon an absolute basis Dale graded the marbles of Vermont into six classes, based upon average grain diameter, as follows: Extra fine, 0.06 millimeter; very fine, 0.10; fine, 0.12; medium, 0.15; coarse, 0.24; and extra coarse, 0.50.

Rift or Grain.—While the terms "rift" and "grain" have distinctive meanings as applied to sandstone and granite, in connection with marble they are used synonymously for the direction of easiest splitting. The rift usually parallels the bedding, and it is probably due to elongation of grain caused by pressure. It may be emphasized by the presence of platy or fibrous minerals, such as scales of mica or graphite or needles of actinolite. These usually occupy positions with their long axes parallel to the direction of grain elongation and thus increase the tendency to split in that direction. Quarrymen find it advantageous to follow the direction of easy splitting, for thus wedges may be placed much farther apart than where no rift exists.

Porosity.—Porosity is the volume of pore space expressed as a percentage of the total volume of a rock mass. The pore space of high-grade marbles is usually very small, ranging from 0.0002 to 0.5 per cent. A fine-grained marble may have more pore space than one of coarser texture, but the opposite is more often true. Low porosity in exterior marble is desirable, as pores permit infiltration of water, which may dissolve or discolor the stone or cause disintegration by freezing. Porous stones also collect soot or particles of soil and therefore are not satisfactory when exposed to excessive smoke or dust. Practically all marbles recommended for exterior use have very low porosity.

Strength.—The strength of marble is the measure of its capacity to resist stresses of various kinds. It depends partly on the rift, on the cleavage and hardness of the grains, and partly on the state of aggregation, including degree of cohesion, interlocking of grains, and nature of cementing material if such is present. Compressive, transverse, tensional or cohesive, and shearing strength all affect use, but compressive strength is the quality most commonly tested.

Although strength alone is not a sure criterion of durability, knowledge of the capability of any stone to withstand stresses of various kinds has great value if the material is to be used for purposes involving extraordinary strains. Practically all commercial grades of sound white marbles can support many times the weight of structures in which they are ordinarily used, though some brecciated and veined marbles are too weak to sustain heavy loads with perfect safety. As a rule, marble is stronger across the bedding plane than parallel to it. Compressive strength has no significance in judging the quality of cemetery memorials.

Transverse strength indicates the suitability of a marble for door or window caps or for bridging material that must bear heavy loads. Breakage of caps, however, must not always be attributed to weakness in the material employed, as unequal settling or improper laying may be the chief cause.

When subjected to crushing strain rocks can be compressed appreciably before rupture occurs. A measure of this compressibility in terms of the load is what is known as the modulus of elasticity. The compressibility of marble is so small that it has little significance, except possibly in calculating the effect of a very heavy superstructure on a masonry arch or in proportioning abutments and piers of massive bridges. A high modulus of elasticity is desirable in marble subjected to minor stresses and strains due to settling of buildings.

JOINTING OR UNSOUNDNESS

Meaning of Unsoundness.—The term "unsoundness" refers to all cracks or lines of weakness other than bedding planes that cause marble to break before or during manufacture. The various types are known locally as "joints," "headers," "cutters," "hair lines," "slicks," "seams," "slick seams," "dry seams," or "dries," and "cracks." The term "reed" is applied to a weakness that parallels the bedding.

Nature and Importance of Joints.—Most joints, as they appear in marble deposits, are straight and uniform, though some may be curved or irregular. Some are open and conspicuous and others so obscure that they can be recognized only by long and constant practice on the part of those skilled in their detection. The spacing of joints is variable. They tend to occur in groups of closely spaced fractures, separated by masses which contain few joints. In certain Vermont quarries such closely spaced groups are termed "fish-backs." In some deposits joints may be 10 to 30 feet apart, in others, separated by only a few inches. Needless to say, wide spacing adds greatly to the commercial value of a deposit.

Origin of Joints.—Authorities generally agree that joints are caused by strains in rock masses. As pointed out in the chapter on granite, a compressive force in one direction will develop two systems of joints at right angles to each other, and at angles of 45° to the line of pressure.

Torsional forces or earthquake shocks alone or in conjunction with other forces may have a similar effect. Both direction and spacing, as observed at the surface, may persist with remarkable uniformity at depths of 100 feet or more.

Therefore, according to the theory noted in the paragraph immediately preceding, which is supported by results of many observations, joints tend to occur in regular systems. Two systems approximately at right angles to each other are not uncommon. Occasionally a third or fourth system may appear. Exceptionally no well-defined systems can be recognized. The systematic arrangement is recognized by most quarrymen and is an important factor in the economy of marble working. Greater loss results from quarrying without regard for unsoundness than from any other cause. Operators may augment the proportion of sound stock by making careful study and detailed diagrams of all visible unsoundness and by quarrying in conformity with it. That is, walls should be made to parallel the major joint systems, and all subsequent cuts so arranged in spacing and direction that seams will intersect blocks as little as possible. Blocks intersected by oblique joints are almost useless.

Unsoundness in Verde Antique.—Joints in serpentine marble, or what commonly is called "verde antique," usually are rather abundant and extremely irregular. They are probably caused chiefly by expansion or swelling due to hydration as the serpentine is formed. Consequently, joints are usually less systematic in this variety than in white marbles, and large, sound blocks are more difficult to obtain. Occasionally the cracks are recemented by crystalline calcite, which produces an attractive white veining on a green background. The so-called brecciated marbles are composed of many irregular and usually angular fragments that have been cemented by chemical precipitation of calcium carbonate.

Glass Seams.—Joints that have been recemented in nature are sometimes termed "glass seams." They may be strong enough to permit sawing the marble even into thin stock, but such seams are usually planes of weakness. The filling is generally calcite, though occasionally silica in the form of quartz, flint, or chert. A siliceous filling is least desirable because its extreme hardness makes sawing and polishing difficult, and because its surface is nonuniform. In any case, a glass seam usually appears as a conspicuous line which can be regarded only as a blemish when present in otherwise uniform marble.

CHIEF IMPURITIES OF MARBLE

Iron Sulphides.—The chief iron sulphides in marble are pyrite and marcasite, which have the same chemical composition (expressed by the formula FeS_2), though they differ in crystal form. In many marble

deposits they are accessory minerals, pyrite being the more common, and may appear as scattered crystals of variable size or form prominent bands and masses. Decomposition of the sulphides may result in undesirable discolorations, consisting of iron oxides.

Most authors who have discussed impurities in building stone have stated unreservedly that pyrite is injurious when the stone is used for exterior work. This statement is not always true, however. Although the sulphides in some marbles decompose and form undesirable discolorations in a few months, those in marble from other deposits may withstand many years of weathering and show no appreciable change. Some American marbles containing pyrite have been exposed to the weather for more than 100 years without noticeable staining.

Pyrite is usually more stable than marcasite. Solid crystals of either mineral usually decompose slowly, though finely divided granular or porous forms of either alter rapidly. Mixtures of pyrite and marcasite decompose more readily than the pure minerals. A fair conception of the probable stability of the sulphides in a marble may be gained by making observations and tests. The most reliable information is obtainable by observing stain effects on structures of sulphide-bearing marble or on weathered outcrops of the deposit from which it was obtained. Iron sulphide is not necessarily injurious in marble but should be avoided carefully in the selection of stone for exterior uses where discoloration is undesirable. In some instances, however, discoloration by weathering may not be detrimental, for such color changes may blend with the normal mellowing and ageing of the stone.

Marble containing pyrite may be used to advantage for interior structural or ornamental purposes, as bands and patches of the iron sulphide minerals produce beautiful effects on polished surfaces. Pyrite crystals are very hard, however, and may injure tools used in cutting.

Silica.—Knots or bands of silica derived from skeletal remains of organisms may be original constituents of marble. Silica may also be introduced into a marble bed at a later stage in the history of the deposit. Water that percolates through fissures in the mass may contain small quantities of silica in solution, which may be precipitated in cracks and cavities. Silica in this form tends to follow unsoundness and may even effectually seal fractures. The presence of silica usually detracts from the appearance of marble. As a rule, the flinty or cherty mass differs from the marble in color or texture and constitutes a blemish comparable to that produced by a knot in an otherwise uniform stick of timber. Occasionally, however, flinty masses are the basis for distinctive decorative markings that are an asset to the stone. Silica is at least twice as hard as ordinary marble, consequently, it greatly retards channeling, drilling, or sawing and injures tools, especially wire saws. A flint ball may divert a saw to one side or may greatly reduce the rate of cutting.

Moreover, uniformity of finish under a buffer is difficult to obtain on the surface of a flinty marble on account of its unequal hardness.

Silicated Marbles.—Silicated marbles contain pyroxenes, amphiboles, mica, chlorite, or other silicates which are commonly formed by alteration of interbedded impurities. Marbles may therefore contain bands of these minerals, which sometimes remain conformable with the original bedding. In such form they are not serious imperfections and may even facilitate quarrying. However, silicate impurities, especially mica and chlorite, may be scattered throughout the mass in dark bands and patches which generally detract from the market value of the stone although at times they may be adapted to ornamental use.

Dolomitic marbles may contain tremolite, a silicate of calcium and magnesium. The mineral generally occurs in the form of white crystals with a silky luster and a characteristic diamond-shaped cross section. They may be microscopic in size or may attain a length of 2 inches, and are much harder than marble. Wollastonite, diopside, olivine, and tourmaline are other common silicates present in marbles.

Dolomite in Marble.—Marble composed of alternating masses of dolomite and calcite is undesirable. When dolomite is present in lenses or bands, the resulting unequal weathering will produce a nonuniform surface. Differences in texture, color, or susceptibility to polish of the two minerals are also probable. Although pure dolomite, or intimate mixtures of dolomite and calcite, is not to be regarded as an inferior type of marble, heterogeneous mixtures in the form of lenses, knots, or bands are undesirable for the reasons given.

GEOLOGIC INTERPRETATIONS

Intimate knowledge of the geology of marble deposits is a practical necessity for intelligent quarry development. Beds of high quality must be followed, and this demands an understanding of their stratigraphy, including folding and faulting. The origin and occurrence of imperfections should be known. Operations also depend upon rock structures, such as joints and dikes.

The quality of a marble tends to be fairly constant throughout a given bed over wide areas. An adjoining bed, even though only a few feet away, may have been deposited much later or earlier and under vastly different conditions. Therefore, the greatest changes in quality and character of rock are found in passing from one bed to another. To obtain high quality and uniformity in the product the bedding must be followed closely. Each bed generally is designated by a particular name, and quarrymen usually are so familiar with characteristics of successive strata that they can assign a block in a stock pile to its proper bed by visual examination. This intimate knowledge of stratigraphy is exceedingly practical in recognizing desirable beds in new openings made along

the strike or in outcrops where beds reappear at the surface through folding or faulting. Certain beds may be traced for many miles and may maintain remarkable uniformity in quality and thickness. They may, however, narrow, widen, or disappear entirely, and the quality may change.

USES

Marble is used mainly for buildings and monuments, interior decoration, statuary, and novelties.

In exterior building marbles qualities of endurance rank equally in importance with appearance. For such outdoor uses, therefore, marbles should be strong, uniform, close-grained (though not necessarily fine-grained), reasonably nonabsorptive, and free from impurities that may stain or corrode the surface. While uniformity in color was once desirable, the present tendency is toward blending of mixed colors.

For interior decoration, appearance is the prime factor determining value. Both pure white and variously colored marbles are applied to the various uses, including floors, steps, baseboards, columns, balusters, wall panels, wainscoting, and arches. That used for floors and stair treads should be reasonably resistant to abrasion. Brecciated marbles, most of which are imported, are widely used for columns and wainscoting. Verde antique is popular for interior decorative effects. It is used sometimes as an exterior ornamental stone as, for example, on banks and store fronts. Onyx marble is popular for interior decoration, as it has a wax-like appearance and attractive banding. Interior marble is used in various minor ways, such as for table tops, lavatory fittings, and sanitary work generally.

Statuary marble is the most valuable variety quarried. It must be pure white, uniform and usually fine-grained in texture, and somewhat translucent, and must have marked adaptability for carving. Numerous statuary and decorative marbles from American quarries are now on the market, each having its own particular trade name.

All the more ornamental types are used for novelties. A favorite use of onyx is for the manufacture of gear-shift balls. Onyx, verde antique, and true marbles are manufactured into inkwells, lamp bases, smoking sets, clock cases, paperweights, and various other gift-shop novelties.

Waste marble is used as crushed stone, terrazzo, stucco, and riprap, for lime, for fluxing, and for various chemical uses covered in a later chapter on limestone. Waste blocks are also cut into convenient sizes for ashlar used in house construction.

DISTRIBUTION OF DEPOSITS

As recrystallization, the outstanding characteristic of marble, is promoted chiefly by heat and pressure acting on the original limestone,

most marbles are confined to areas of extreme folding or igneous intrusion, hence, occur chiefly in mountainous regions. The important marble belts of the United States are in the Appalachian region of the Eastern States and in the Rocky Mountain and Coast Ranges of the West. Deposits also occur in several Central States and in Alaska.

The Appalachian belt, which is the most productive, follows a comparatively narrow, well-defined course as shown in figure 29. Beginning at the Canadian border in northern Vermont it extends due south through western Massachusetts and Connecticut and eastern New York to within a short distance of New York City. No marble of consequence

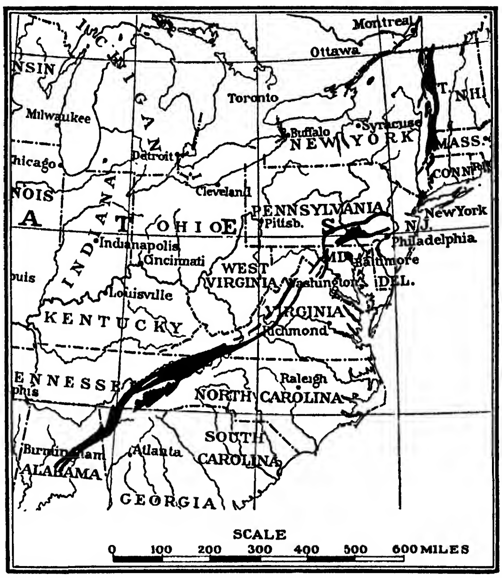

FIG. 29.—Map showing marble deposits of eastern United States. (*Prepared by H. Herbert Hughes.*)

occurs in New Jersey, except in the extreme west, but the belt reappears prominently in southern Pennsylvania and extends southwestward through Maryland, Virginia. North Carolina, Tennessee, Georgia, and Alabama.

Marbles of the Central States occur in isolated localities, principally Minnesota, Missouri, and Texas. For the most part, recrystallization has been accompanied by very little, if any, deformation of beds.

Various types of marbles are found in the Rocky Mountain and Pacific Coast States (in parts of California, Nevada, Montana, and Colorado, with more restricted areas in Idaho, southwestern Oregon, and northeastern Washington) but many are too inaccessible to have commercial importance at this time.

PRODUCTION

The volume in cubic feet and value of marble sold in the United States over a period of years are shown in the following table by uses:

MARBLE SOLD BY PRODUCERS IN THE UNITED STATES, 1924–1937, BY USES

Year	Building stone				Monumental stone		Total	
	Exterior		Interior					
	Cubic feet	Value	Cubic feet	Value	Cubic feet	Value	Cubic feet	Value
1924	852,940	$2,621,088	1,753,240	$6,178,131	1,230,450	$3,858,190	3,836,630	$12,657,409
1925	1,145,690	3,559,686	1,719,610	6,040,425	1,176,090	,3,598,907	4,041,390	13,199,018
1926	1,123,990	3,350,434	1,743,950	6,069,505	1,095,220	4,047,857	3,963,160	13,467,796
1927	850,470	2,826,079	1,973,320	7,913,149	1,127,480	4,097,249	3,951,270	14,836,477
1928	1,019,490	3,146,202	2,005,150	8,963,125	1,031,050	3,749,269	4,055,690	15,858,596
1929	924,420	3,849,510	1,854,380	8,276,206	1,065,760	3,885,481	3,844,560	16,011,197
1930	772,920	2,685,924	1,698,180	6,390,107	879,270	3,263,383	3,350,370	12,339,414
1931	594,710	2,986,901	1,066,640	4,855,595	637,830	2,177,656	2,299,180	10,020,152
1932	863,690	2,213,673	818,160	3,413,929	432,590	1,669,689	2,114,440	7,297,291
1933	760,420	2,396,571	583,890	2,481,167	426,300	1,358,770	1,770,610	6,236,508
1934	190,060	523,033	309,950	1,196,423	464,910	1,475,426	964,920	3,194,882
1935	150,560	494,097	217,890	1,212,173	300,370	1,521,681	668,820	3,227,951
1936	373,520	1,701,864	398,440	2,079,010	374,520	1,751,947	1,146,480	5,532,821
1937	284,500	938,570	447,200	2,397,975	360,580	1,798,176	1,092,280	5,134,721

MARBLE SOLD BY PRODUCERS IN THE UNITED STATES, 1929, BY STATES AND USES

State	Building and monumental (rough and finished)		Other uses		Total	
	Cubic feet	Value	Short tons	Value	Short tons (approximate)	Value
Alabama	52,900	$ 381,781	36,400	$ 61,738	40,900	$ 443,519
California	14,260	71,259	1,570	9,575	2,780	80,834
Georgia	676,190	3,739,825	26,300	37,450	82,920	3,777,275
Massachusetts	19,720	97,910	2,510	3,542	4,180	101,452
Missouri	477,010	927,530	15,900	4,941	55,420	932,471
New York	51,220	129,202	44,160	187,760	48,640	316,962
Tennessee	1,312,180	5,678,596	58,950	60,408	169,630	5,739,004
Vermont	1,185,100	4,763,471	29,350	35,242	129,940	4,798,713
Other States*	55,980	221,623	14,490	133,459	19,250	355,082
	3,844,560	$16,011,197	229,630	$534,115	553,660	$16,545,312

* Alaska, Arizona, Arkansas, Colorado, Idaho, Maryland, Montana, New Jersey, North Carolina, Utah, Virginia, and Washington.

The eight leading States, in order of production value in 1929, were Tennessee, Vermont, Georgia, Missouri, Alabama, New York, Massachusetts, and California. The preceding table, compiled by the Bureau of Mines, shows the total marble production during 1929 by States. These figures are given in preference to those of later years, when conditions were more disturbed.

In 1929, 111,580 cubic feet of verde antique (serpentine marble), valued at $842,058, was sold in the United States; in 1930, 98,490 cubic feet, valued at $695,131; in 1931, 39,150 cubic feet, valued at $218,098; and in 1937, 16,300 cubic feet, valued at $145,136.

INDUSTRY BY STATES

Occurrences of marble in the United States are described in the following pages by States in order of their production value in 1929, as that year was probably more nearly normal than the three succeeding years. Descriptions are confined chiefly to deposits in which quarries have been recently in operation, minor attention being given to unworked areas or abandoned quarries.

Tennessee.[24]—As the preceding table indicates, in 1929 Tennessee produced 1,312,180 cubic feet of building and monumental marble, valued at $5,678,596, or about 35.5 per cent of the total value of marble produced in the country. Production in 1930 was 1,019,300 cubic feet, valued at $3,355,673; in 1931, 525,900 cubic feet, valued at $2,407,878; and in 1937, 267,370 cubic feet, valued at $1,384,961.

General Distribution.—The widely known marbles of east Tennessee occur in rocks of Palaeozoic age in what is known as the Holston member of the Chickamauga formation. The latter formation is of wide extent and consists chiefly of limestone. The Holston beds are confined to the Tennessee River Valley and outcrop in a series of nearly parallel bands. The area is 12 to 16 miles wide and over 125 miles long. Marbles of commercial quality occur in many places, and the supply is practically inexhaustible. Two important railway lines traverse the area—the Southern Railway, which extends throughout its length, and the Louisville & Nashville Railway, which crosses it.

Tennessee marble was used locally for tombstones in very early days; but the history of production as an industry dates from 1838, when the United States Government opened a quarry in Hawkins County to provide interior marble for the Capitol at Washington. During ensuing years other quarries were opened until an industry of great magnitude was developed.

[24] Data on Tennessee marble deposits have been compiled chiefly from Tennessee Geol. Survey Bull. 28, Marble Deposits of East Tennessee, by Gordon, Dale, and Bowles, as recorded in the bibliography at the end of this chapter. This information was supplemented by that obtained during visits to most of the quarries by the author.

The belts of the Knoxville district are shown in figure 30, which is modified from Gordon's index map.[25] The seven belts shown in the figure lie in approximately parallel positions running southwest and represent a series of folds resulting from lateral pressure exerted northwest-southeast. Named in order, from northwest to southeast, they are: Luttrell belt, Black Oak belt, Concord belt, Knoxville belt, French Broad belt, Meadow belt, and Bays Mountain belt. The Galbraith belt in Hawkins County is regarded as a continuation of the Black Oak belt. The Meadow belt was described later than the others and does not appear in the sketch. Although some good marble is quarried near the boundaries

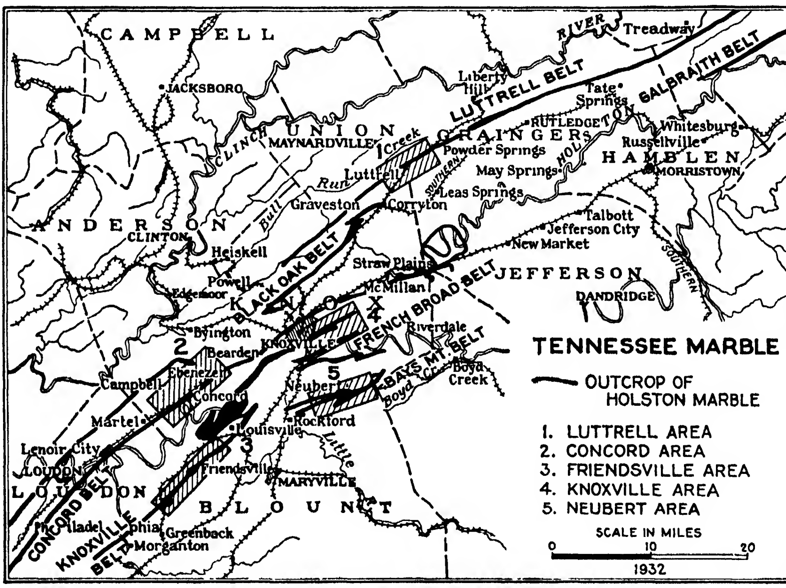

FIG. 30.—Map showing marble deposits of eastern Tennessee.

of the formation, by far the best and most productive quarries are those near the middle of the area.

Luttrell Belt.—The Luttrell belt about 55 miles long extends from Hawkins County southwestward without interruption to about 8 miles north of Knoxville. As it fringes the northwestern boundary of the basin, it contains much earthy and shaly matter. Good marble abounds in many places; but owing to narrow outcrops and heavy stripping, conditions do not favor development.

Black Oak and Galbraith Belt.—The Black Oak belt begins at Corryton and extends southwestward through Fountain City to a point about 5 miles northwest of Knoxville, where it is interrupted by faulting and

[25] Work cited, p. 27.

erosion. It reappears 6 miles farther on and continues into Monroe County. Near Corryton the outcrop is one half to three fourths mile wide, but throughout the remainder of its course rarely exceeds one fourth mile. Many impure limestone and shale beds appear with the marble.

A northeastern extension known as the Galbraith belt occurs in central Hawkins County and in near-by Virginia. Folding at this point has been so great that the beds are overturned, bringing the Knox dolomite above the marble, which occurs in massive layers and is predominantly dark red or chocolate. Splashes of white in places represent crystallized remains of bryozoans, corals, and other organisms.

Numerous quarries have been opened in this area, and some are the oldest in the State. The Dougherty or National quarry supplied stone for the United States Capitol. Much of the marble was used for table and dresser tops, but with the decline of this fashion and a growing demand for pink and gray, production has ceased in this vicinity.

Concord Belt.—The southwestern extremity of the Concord belt is at Sweetwater, whence it extends northeast past Loudon, Lenoir City, and Concord through the northern outskirts of Knoxville and ends near Strawberry Plains in a closed loop about 4 miles across. In general, earthy and shaly beds are less prominent than in the belts to the north, while the marble becomes proportionally thicker, except in a section near Knoxville where the belt is thin. The Southern Railway follows this belt closely throughout its entire length, and in several places the Tennessee River intersects it.

Knoxville Belt.—The Knoxville belt, where much excellent marble is quarried, appears several miles southeast of Sweetwater, Monroe County, and extends northeast through Friendsville, Louisville, and southern Knoxville to the vicinity of Ruggles Ferry on the Holston River. Near the two extremities of the belt the rocks dip southeast at an angle of about 30°, but near Louisville they lie more nearly horizontal. This accounts for the wide outcrop which appears just beyond the northern corner of the Friendsville area, as shown on the map. Many quarries have been opened on the belt from the railway station at Meadow to the northern extremity. The prevailing marble is a popular shade of pink, with smaller quantities of chocolate and gray.

French Broad Belt.—The French Broad belt is shaped like a great U, with its base about 3 miles southeast of Knoxville and its sides extending northeast 8 or 9 miles. Locally it is sometimes called the "wishbone." The shape is due to the planing off by erosion of a southwestern pitching anticlinal fold. The northern arm of this fold is the center of a thriving quarry industry. The marble formation is about 300 feet thick, and about half is of commercial grade. Several active quarries are situated near the junction of the Holston and French Broad Rivers.

Meadow Belt.—The Meadow belt, which is not shown on the map as a separate band, is quite close to the Knoxville belt. It has been traced from near Miser southwestward to a point beyond the railway station at Meadow, at which place it has been quarried to some extent.

Bays Mountain Belt.—This, the southernmost of the marble belts, is situated along the north side of Bays Mountain 5 to 7 miles southeast of Knoxville. It is chiefly in Knox County, though it extends a short distance into Blount County. The widest outcrop is near Neubert Springs, where the exposure forms the base of a U-shaped loop which opens to the southwest as the result of the planing off by erosion of a northeast-pitching anticlinal fold. As this belt is near the southern boundary of the marble basin it contains more silty and shaly materials than the central belts. The beds have a maximum thickness of about 300 feet.

Productive Areas.—The Hawkins County area, which is now unproductive, has been described briefly in the section devoted to the Galbraith belt. The five productive areas outlined in rectangles on the sketch map, figure 30, and designated 1, 2, 3, 4, and 5, are briefly described in order as follows.

LUTTRELL AREA.—The only important quarries are at Luttrell and are situated on the lowest bed of the Luttrell belt. This bed is about 75 feet thick and dips 32° in a direction S.35°E. Mud seams 12 to 20 feet apart run N.50° to 55°E. A series of seams or cutters spaced at moderate intervals runs N.60° to 80°W. A light red shading into dark red marble of good quality is obtained, and waste is burned into lime.

CONCORD AREA.—Several quarries are, or have been, in operation near Concord on the Black Oak, Concord, and Knoxville belts. A quarry which was at one time of considerable importance is on a westward continuation of the Black Oak belt about 3 miles north of Ebenezer. It was opened on a shallow synclinal fold, and the relatively thin layer of overburden and nearly level attitude of the beds offered favorable quarry conditions. The main ledge is a 50-foot bed of light pink marble with heavy ledges of dark red or "cedar" marble above and below. Originally only the dark red was quarried, but later both types were marketed. A prominent series of nearly vertical seams or cutters runs N.40°W. They are spaced 8 to 20 feet apart throughout most of the quarry.

The most prominent beds quarried at Concord are 75 to 80 feet thick, with deep red or chocolate marble in the upper part and light red shading to pink in the lower. The beds dip 30° to 40°, while irregular mud seams are nearly flat or slant at a moderate angle. The quarry is near the river, and in early years much of the product was shipped by water. A large part of the waste marble has been burned into lime.

For many years several quarries were worked about 4½ miles south of Ebenezer, but only one has been in operation recently. It is an important producer and provides an attractive grade of pink marble known to the trade as "Bond Pink."

FRIENDSVILLE AREA.—The productive area on the Knoxville and Meadow marble belts extends from the station at Meadow to Louisville; Friendsville is about the middle of the district. In this area about 26 active and abandoned quarries have been noted, but not more than five or six have produced during recent years.

The most southerly active quarries are about 1¾ miles west of McMullen station, where very sound marble occurs in beds about 120 feet thick, the upper 50 feet being red and the remainder light pink to gray. The principal development has been during the past few years, and much high-grade marble is now produced.

About 1½ miles east of Friendsville is a second group of active quarries. As sound, attractive marble is available in large blocks, this is the most productive part of the district. Pink and red marbles are most abundant, although gray is also found. The most southerly of the three openings uncovers beds about 75 feet thick, and the best grade is found in the lower 25 feet. The marble, covered with a moderate overburden of sandy soil, dips under the hill at an angle of about 15°. Many mud seams appear near the surface, but cutters in the rock are rare. At the second and third openings to the north the overburden becomes much heavier, and underground methods employing modern electric-driven equipment are used. Part of the waste is ground and sold as agricultural limestone. Two miles west of Louisville a similar pink marble is quarried, and is marketed under the trade name "Anderson Pink." It is of good quality and available in large, sound blocks.

KNOXVILLE AREA.—The Knoxville area, occupying the center of the marble valley, is about 3 miles wide and 6 miles long and extends northeastward from Knoxville along the valley of the Tennessee River beyond the junction of its tributary streams, the Holston and French Broad Rivers. An abundance of high-grade rock is available in this territory and usually at least a dozen quarries are in active operation.

About 4½ miles east of Knoxville the deposit is extensive and has been worked for many years. A group of quarries provides high-quality light pink and gray marbles, which are well-suited for structural uses and for carving. Much of the waste is burned into lime. These quarries are on the northern limb of the French Broad belt, which extends eastward through the loop of the river at the Forks. East of the Forks is an important group of quarries extending about 2 miles east of the river, where good-quality pink and gray marble is quarried by several companies. In places, fissures and solution cavities increase the difficulty of quarrying. The Knoxville belt to the north provides another important quarry area,

particularly in the section between the Tennessee and Holston Rivers, 1½ to 4 miles northeast of Knoxville. In the western part of this section the beds are 150 to 200 feet thick, with pink marble in the bottom, gray above, and some of the darker reds near the top. The chief output is of the light gray type, which is very attractive for interior decoration. The quarries farther east produce high-grade, light pink marbles.

NEUBERT SPRINGS AREA.—Marble has been quarried to some extent on the Bays Mountain belt near Neubert Springs about 8 miles directly southeast of Knoxville. The bed dips about 75°, an unusually high angle in the Tennessee district. This area is close to the southern fringe of the marble valley, so an excessive amount of impure material is mixed with the good marble. Although pink and gray marbles of good quality are available, the proportion of waste is high.

Characteristics of Tennessee Marbles. JOINT SYSTEMS.—Two complementary sets of major joints prevail throughout the region, one set striking N.40°–60°E., and the other N.40°–60°W. Weathering tends to follow the joints, forming solution cavities which have been filled with residual reddish clay. When the clay is removed the marble surface in some districts consists of irregular prongs 5 to 20 feet high and 2 to 10 feet apart at the base. As solution tends to follow all planes of weakness the prongs usually consist of sound high-grade marble. Operations on these irregular surfaces are known locally as "boulder quarries."

FOSSIL CONTENT.—Tennessee marbles consist mainly of calcareous remains of two kinds of marine invertebrates—crinoids and bryozoa. Secondary crystallized calcite encloses the crinoidal fragments and fills the bryozoan cells, as well as all the interstices. Unlike most marbles those of the Knoxville district are not highly metamorphosed, and multitudes of fossils show no distortion, recrystallization evidently having involved only slight deformation.

"CROWFOOT" STRUCTURE.—The most characteristic structures of Tennessee marbles are the stylolites known locally as "crowfoot." They are irregular or zigzag grayish, black, greenish, or reddish suture planes. The markings, which occur in bands usually 1/10 to 1 inch wide, generally parallel the bedding and are from a few inches to several feet apart. These irregular markings appear prominently on marble steps, floor tile, and wainscoting in innumerable public buildings throughout the country. The origin of stylolites is somewhat obscure. It is assumed that they consisted originally of thin bands of carbonaceous and iron-bearing shales. Percolating acid waters attacked the beds above and below the shale, dissolving the marble and leaving very irregular surfaces. The pressure of overlying strata, or that occasioned by folding, forced the beds together, and with intermeshing of projections above and below the shale was pressed into all irregularities. Later faulting and dislocation made the crenelations even more irregular.

TEXTURE.—In general, Tennessee marbles consist of calcite grains in a groundmass of disintegrated bryozoa. Most of them are fine-grained, but owing to the presence of larger scattered fossils many are variable in texture. In all but the coarse, dark marbles of Hawkins County the crinoidal remains, with the secondary calcite about them, make up approximately one third of the rock and the bryozoa about two thirds. Because of the fineness and irregularity of the groundmass the rock is much stronger than uniformly crystallized marbles.

Physical Properties.—Dale[26] has divided Tennessee marbles into six groups on the basis of color, as follows: (1) Gray; (2) faintly pinkish gray; (3) pink (subdivided into light, medium, and dark); (4) fine dark red; (5) coarse dark red; and (6) variegated. The gray and pale pink varieties are used most widely. The marbles are of a high degree of purity, with a calcium carbonate content of about 99 per cent. Even those of chocolate color have an iron content of not more than 0.5 per cent. Chemical purity is attributed to the almost exclusively organic origin of the calcareous sediments. Tennessee marble is of low porosity, the pore space averaging, according to tests by the U. S. Bureau of Standards, about 0.5 per cent; it is much lower in some varieties.

The marble of this State is highly resistant to abrasion and therefore is well-suited for use as floor tile and stair treads. Notable examples of use are the concourses of the Grand Central and Pennsylvania Stations in New York, where for many years Tennessee marble tile has withstood the wear of intensive pedestrian traffic.

Manufacture and Distribution.—Many large, well-equipped mills are in operation in and about Knoxville, where marble is manufactured into a great variety of architectural and ornamental forms particularly for interior use. Great quantities of marble are also shipped in rough blocks to mills in the larger cities in all parts of the country.

Vermont.[27]—In 1929 Vermont produced 1,185,100 cubic feet of building and monumental marble, valued at $4,763,471, or about 29.8 per cent of the total value of marble produced in the United States during that year. Production in 1930 amounted to 1,098,080 cubic feet, valued at $4,206,456; in 1931, 905,280 cubic feet, valued at $3,187,431; and in 1937, 302,100 cubic feet, valued at $1,539,571.

General Features of Marble Belt.—The great marble belt of western Vermont, which is about 80 miles long, lies chiefly between the Green Mountains and the parallel Taconic Range to the west, a valley ranging in width from ¼ mile to 4 miles. To the south, from Pine Hill to Danby Hill, the marble lies between the Taconic Range and an

[26] Dale, T. Nelson, Work cited, p. 146.

[27] The principal data on Vermont marbles were obtained from U. S. Geol. Survey Bull. 521, The Commercial Marbles of Western Vermont, by T. Nelson Dale, supplemented by visits of the author to nearly all the quarries.

intermediate range and it also extends north of the Taconic Range, ending between Middlebury and Bristol. A parallel occurrence of marble, known as the West Rutland belt, is about 6 miles long and ½ mile wide. This lies west of Rutland and occupies a minor longitudinal valley through which the Castleton River flows.

When in normal position a slaty schist overlies the marble, and a dolomite lies beneath, but in places these relations are disturbed by faulting. Records of drill cores and data from sections at the quarries show that the thickness of the marble ranges from 335 to more than 850 feet. The beds were no doubt originally laid down as horizontal limestone strata in the sea bottom, but in consequence of powerful crustal contraction which operated mostly west-northwest to east-southeast the limestones were recrystallized into marbles and at the same time intensely folded and in places even faulted. The strike of the folds is generally north and south, although in places it varies somewhat. During subsequent ages crests of folds were eroded away, leaving the marble exposed. At a still later period cross fractures were formed through which a dense, molten-rock magma was injected, forming trap dikes. These are 2 inches to 25 feet wide but are not numerous.

Important Geologic Features. COMPLEXITIES CAUSED BY FOLDING.—Rocks of the great marble belt of Vermont have been intensely folded. Most beds are steeply inclined, the only horizontal ones being sections in the bottoms of the troughs or tops of the arches. As folds are repeated a single bed may appear in a succession of outcrops and lateral folding may complicate greatly the problem of tracing their course. For example, an offset of one fourth mile in the position of certain well-defined marble beds at West Rutland has been attributed to a sharp double lateral fold in the form of the letter S. It will be seen that if the upper and lower parts of the letter are continued as horizontal lines, the upper to the right and the lower to the left, they will represent the same bed following the same direction but will be offset from each other by the width of the letter.

EFFECT OF PITCH OF FOLDS.—The axes of folds are rarely horizontal, but the degree of pitch is usually small—5 to 20°. The practical effect of the pitch is to cause variation in the distance of a bed from the surface as a quarry is advanced along the strike. If the advance is made in the direction of dip a desirable bed plunges deeper and deeper beneath the surface, and in time reaches a point beyond which it can not be worked economically. If a quarry is advanced in the opposite direction the bed gradually comes closer to the surface until it runs out.

JOINT SYSTEMS.—Major joints generally appear in systematic arrangement. The most prominent set strikes N.65°–80°W., with a complementary set N.10°–20°E. A second system strikes N.75°–80°E., with its complementary system N.10°–20°W. Diagonal joints occur in places.

FAULTING.—"Faulting" is a geological term applied to rock fracturing with movement along the fractured surface, resulting in dislocation or change in relative position of beds. The amount of dislocation is known as the "throw" of the fault. Wherever sharp folding is found, faulting is likely to occur. In many places in western Vermont the displacement is only a few feet; in others it may be several hundred. When a major fault plane is encountered in quarrying, the first step is to ascertain the direction of throw and extent of displacement. Even a skilled geologist may have difficulty in interpreting the structure, and core drilling may be necessary before the continuation of the lost beds is discovered.

EFFECT OF DIKES.—Trap dikes usually occur in regions of close jointing. Small branching dikes may invade the marble on both sides of the larger ones. Both close jointing and lateral intrusions discourage quarrying close to dikes. Most dikes in Vermont follow a course about N.60°–70°E., and the next most prevalent direction is N.25°–40°E.

EFFECT OF EROSION.—Exposure of marble beds at the surface is due to removal of overlying schist by erosion, which at the same time carried away much marble, leaving truncated folds. Where either an anticlinal fold (arch) or synclinal fold (trough) has been truncated by erosion remnants of both limbs of the fold must remain in the earth. If only one appears in an outcrop it may be possible to locate the other by reconstructing in theory the original structure and estimating its probable width at the point of truncation. Such a truncated major fold is in evidence south of West Rutland, for the beds of both the east and west limbs have been found. Naturally beds on the east side appear in reverse order to those on the west. Ability to picture reconstruction of the marble folds has great practical value in facilitating search for remnants of beds that may be concealed by glacial débris.

EFFECT OF WEATHERING.—Long centuries of weathering on exposed surfaces or on rock covered with sand or gravel generally have resulted in alteration of marble to a depth of 15 or 20 feet, and such material must be discarded as waste. Exceptionally, marble exposed at the surface is of good quality, but usually some alteration has taken place unless a covering of glacial till or water-worked clay has protected it from weathering effects. In some places the imperviousness of clay has preserved the most delicate glacial striations, and good marble may be quarried within a few inches of the surface.

General Succession of Beds.—Throughout many parts of the marble belt a definite succession of workable beds may be traced. Beginning at the overlying schist the succession as given by Dale[28] is as follows: (1) Upper graphitic marbles; (2) white graphitic and muscovite marbles alternating; (3) upper clouded light gray marbles; (4) intermediate dolomite; (5) lower clouded white marbles; (6) lower graphitic marbles.

[28] Dale, T. Nelson, Work cited, p. 96.

The entire succession is present at few, if any, localities; certain beds are prominent in one region, while others furnish the chief supply at another point. At West Rutland the average thickness of all workable beds was estimated by Dale as 783 feet and at Proctor as 616 feet. This belt no doubt contains an extensive reserve supply of marble.

Character of Marbles.—Commercial marbles that abound throughout the valley are of a high degree of purity; many consist of 98 to more than 99 per cent calcium carbonate. Porosity is low, and colors are attractive for interior or exterior use. They are widely known and are used extensively in all parts of the country.

Individual Quarry Districts.—Marble occurrences in the chief producing districts are briefly described in the following pages, beginning with the most southerly quarries and advancing toward the northern end of the belt.

DORSET MOUNTAIN.—The Imperial quarry is in the southern part of Rutland County about 1½ miles southwest of Danby on the northeastern flank of Dorset Mountain and about 700 feet above the railroad. Both open-pit and underground methods of quarrying have been employed. The rock is a coarse-grained, faintly cream calcite marble, which is somewhat translucent. Joints are fairly regular, and large sound blocks are obtainable. Blocks are conveyed to the railroad by means of cable cars over an inclined railway three fourths of a mile long. The marble is used for exterior and interior building and for memorials. The Amphitheater in Arlington Cemetery near Washington, D. C., was built of stone from this quarry.

The White Stone Brook quarry a short distance south of the Imperial quarry is served by the same cable-car railway. The beds, which total about 100 feet in thickness, dip to the east 5 to 10°. The stone is coarse-grained and white to cream, with faint yellow to greenish gray streaks and spots. It takes a good polish and is used for interior and exterior building.

CLARENDON.—The Clarendon quarry is about 3 miles southeast of West Rutland. The maximum thickness of the beds here is 327 feet. The upper beds are graphitic marbles, the middle beds are white, lightly mottled and banded, while the lowest is a variegated graphitic marble. Major joints strike N.35°W. and are 3 to 7 feet apart. All the marbles take a high polish and are well-adapted for construction. The products are standard Vermont marbles that have been used for many years.

WEST RUTLAND, WEST SIDE.—As previously stated, the structure at West Rutland is a truncated anticline, and the quarries fall into two groups—those on the western limb and those on the eastern. Six large quarries have been in operation on the west side; only one is now active, although others are equipped for production. Marble occurs in a variety of beds, aggregating nearly 200 feet in thickness. Joints are in regular

systems, and their direction and spacing are remarkably uniform, even at depths of 100 to 150 feet. Some of the quarries are very large. Much high-grade marble has been removed from drifts which extend along the beds from the original open-pit workings. Very attractive green, blue, purplish gray, and cream marbles predominate. The products are employed chiefly for interior decoration.

WEST RUTLAND, EAST SIDE.—The eastern limb of the anticline is the most productive region in Vermont. Beginning near the railroad station at West Rutland an almost continuous line of about 12 quarries extends for nearly 1 mile to the north. Those farthest to the south, including the

FIG. 31.—Starting a tunnel 400 feet beneath the surface in a West Rutland, Vt., marble quarry. (*Courtesy of Vermont Marble Company.*)

Covered, New Opening, and Upper Gilson, are in an upper eastern series of beds, and those to the north are in an adjoining western and lower series. The quarries are all narrow openings along the strike, and they follow the dip of the beds, which usually ranges from 35° to 45°E., though in places it curves at steeper or flatter angles. The Covered quarry is the largest in Vermont; it is nearly 400 feet deep and extends about one fourth mile underground to the south. In places the roof of the underground workings is more than 100 feet high and is supported by large square pillars of the original marble beds. An early stage in projecting a new tunnel is shown in figure 31. At the Main quarries long drifts have been projected in the direction of the strike until they meet, which permits the use of electric mine railroads for haulage. In the Main and in the West Blue quarries Nos. 1, 2, 3, and 4 many distinctive beds are encountered, and high-grade white, bluish, greenish, and

pink architectural marbles are produced. Thousands of quarry blocks are kept at West Rutland in a storage yard served by a 50-ton-capacity gantry crane. Lime is manufactured as a by-product.

PROCTOR.—The beds in this locality dip about 60°E. The quarries follow the dip downward and extend along the strike. About five large openings have been made, but recent activity has been confined to the Sutherland Falls quarry. Typical Proctor marble is bluish white and translucent. Very extensive marble-finishing shops are operated at Proctor, and slabs are brought in from various mills up and down the valley.

PITTSFORD.—During recent years the Pittsford district has attained increasing importance. The Pittsford Italian quarry, formerly known as the Turner, is about three fourths mile southwest of the station at Florence in Pittsford township and intersects the same beds as the Proctor quarries. The most typical product is a bluish white calcite marble, mottled with gray. Beds strike N.25°–30°W. and dip 75°E.N.E. Tunnels are extended along the strike.

The Florentine quarry, which is about 1½ miles west of the station at Florence, intersects the upper graphitic beds immediately underlying the Taconic Range schists. The beds strike N.25°W. and dip 60° to 70°W. Structurally the beds belong to the east limb of a syncline. The characteristic product is a dark bluish gray graphitic calcite marble, finely banded with gray and uniformly fine-grained.

The Hollister quarry 1¼ miles northwest of Florence station is a very old opening, which has been extended to a series of seven quarries known as Pittsford Valley Nos. 1 to 7. Nos. 2 and 7 are on the well-known Brandon Italian beds, which have been quarried for many years near Brandon farther north. These quarries are very deep, and many lofty chambers and drifts have been formed by removing all the marble except that left as massive pillars for roof support. The beds strike N.5°W. and are almost vertical, dipping 80° to nearly 90°E. The typical rock is a light bluish gray marble, with irregular mottling due to the recurrence of fine, gray, plicated beds. It takes a high polish, which emphasizes the mottled effect. Generally the marbles are more bluish than those at Proctor. In 1931 eight quarries in this district were either operating or equipped to produce. These quarries are noteworthy for the production of unusually large, sound blocks. Masses weighing 55 to 65 tons have been quarried for the manufacture of monolithic columns. The bowl of Scott fountain, Belle Isle, Detroit, was made from a single block weighing 65 tons obtained from a Pittsford Valley quarry.

BRANDON.—Marble regarded as identical with that obtained in some Pittsford Valley quarries occurs in an excavation about one half mile south of Brandon. It is a mottled, light bluish gray rock suitable for architectural work. A more recently developed quarry has also operated

actively in the Brandon area, producing a standard marble characteristic of this part of the marble belt.

Other quarries have been worked north of Brandon near Middlebury, Monkton, and Bristol, but they have not been active recently.

Economic Features of the Marble Belt.—A discussion of the western Vermont marble belt would not be complete without brief consideration of certain important economic factors. Available water power has been exceptionally advantageous in developing the industry, for several large hydroelectric plants on Otter Creek supply power to practically all the quarries and mills. The sand resources of the marble valley have also been utilized to provide an abrasive for sawing and surfacing the marble.

The marble beds are extremely folded, with enlargement or thinning of certain members, and there are numerous faults. Therefore, many uncertainties confront workers in opening new quarries and in enlarging those now in operation. To minimize the risk of unwise development extensive prospect drilling is constantly conducted. Cores are carefully examined, recorded, and stored in fireproof buildings for future reference. The great volume of information thus accumulated is of inestimable value in interpreting geological structures, estimating reserves, and planning future activity.

Quarry Districts Outside Western Marble Belt.—Although a large part of the Vermont production is confined to the western belt previously considered, there are several important quarry districts outside this area. Four deserve mention, as each produces marble of a type quite distinct from those already described.

SWANTON.—A marble industry has been developed 1 mile southeast of Swanton, Franklin County, near Lake Champlain in northern Vermont. The beds are 150 feet thick. The marbles are described as quartzose dolomites containing fine-grained magnetite. In certain beds the magnetite has been oxidized to hematite, which makes the rock characteristically reddish. Some of the beds are of uniform color; others are mottled red and white. The products are known commercially as "Champlain marbles," and five distinct types are marketed. On account of the high silica content they are difficult to saw and finish. They are highly ornamental and particularly adapted for floor tile and stair treads, as they resist abrasion remarkably well. A finishing mill is operated in connection with the quarry. Similar marble is obtained farther south near St. Albans.

ISLE LA MOTTE.—A marble quarry at the south end of Isle La Motte in Lake Champlain, Grand Isle County, was one of the earliest to be worked in America, having been opened for lime burning in 1664 and reopened in 1788 to furnish building stone. The deposit covers several acres but is shallow. The rock is a fossiliferous calcite marble that has been recrystallized, largely by chemical processes, with little compression

or distortion. Crinoid and gastropod fossil casts show their characteristic circular structure on polished surfaces. The quarried stone is dark gray but when polished appears almost black, with occasional white markings. It is classed commercially with black marbles and is used chiefly for floor tile, base, and wainscoting.

ROXBURY.—A deposit of serpentine 50 to 60 feet wide is quarried about 1 mile south of Roxbury in Washington County, 14 miles southwest of Montpelier. The rock was originally a basic dike, probably consisting of peridotite which has altered to serpentine. Polished surfaces are almost black but are intersected by a network of veins, some of which consist of white magnesite and others of a mixture of magnesite and serpentine, which gives a light green color. Stone from later openings is a lighter green. The color contrasts are exceptionally attractive. The product is sold as "Vermont verde antique" and is widely employed for columns, wainscoting, and various other decoratives uses. Verde antique is also obtained in a northward extension of the belt at Moretown.

ROCHESTER.—Serpentine marbles occur in various parts of Vermont, and new developments are to be expected. A more recent operation than that at Roxbury has been noted at Rochester in the extreme northwestern part of Windsor County, where an attractive verde antique is quarried and shipped to finishing mills in rough blocks. Verde antique is quarried also at Proctorsville, southern Windsor County.

Marble Mills.—Large mills for sawing marble blocks into slabs and other rectangular forms are situated at West Rutland, Center Rutland, and Florence.

Georgia.—In 1929 Georgia produced 676,190 cubic feet of building and monumental marble, valued at $3,739,825, or about 23.4 per cent of the total production of the United States. Separate figures are not available for 1930. Production in 1931 was 497,370 cubic feet, valued at $3,323,421; and in 1937, 197,340 cubic feet, valued at $1,030,407.

Pickens County: GENERAL DESCRIPTION.—The marble industry of Georgia is confined almost entirely to Pickens County in the north-central part of the State, where narrow belts occur in folded strata of Cambrian age. Certain well-defined belts have been described and mapped by Bayley.[29] The Long Swamp Creek belt is about 3 miles long, beginning 2 miles northeast of Jasper and terminating about 1¾ miles north of the railroad station at Tate. Its width ranges from a few feet to 125 feet; the depth is unknown. It consists of a fine-grained, even-grained white rock of sugary texture. According to Bayley's analyses, the marble is very pure, containing 97 to 99 per cent total carbonates. Two analyses show a considerable content of magnesium. It is folded so closely that its structure is hard to interpret.

[29] Bayley, W. S., Geology of the Tate Quadrangle. Geol. Survey of Georgia Bull. 43, 1928, pp. 75–102.

The Marble Hill belt is a hook-shaped area with its barb extending 1¼ miles north of Tate post office and the stem curving around to Marble Hill 2½ miles to the northeast. Beyond Marble Hill the rock again appears in two branches, one extending about 1 mile southwest of the Amicalola quarry and the other southwest about 1½ miles toward Dawsonville. The main section of the belt, which extends from near Tate post office to a point beyond Marble Hill post office, is about 7½ miles long; and many quarry openings have been made in this territory, which provides the great bulk of Georgia commercial marbles. In general, the marbles are of the high-calcium type containing 93 to 99 per cent calcium carbonate. They are very strong and of low absorp-

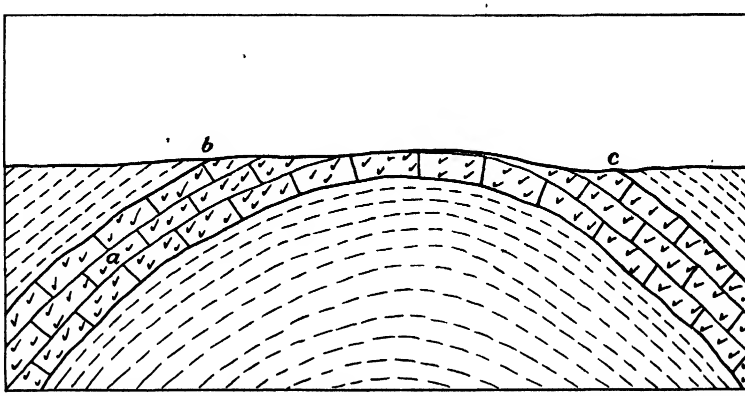

FIG. 32.—Diagram showing how truncation of an anticline may furnish a wide exposure of a narrow bed. *a*, marble bed; *b*, to *c*, marble exposure.

tion, the porosity, according to United States Bureau of Standards tests, averaging about 0.5 per cent. Varieties recommended for exterior use have still lower porosity. They are highly crystalline and of sugary texture. The colors are mostly white, gray, or bluish with subsidiary pink.

The Keithsburg belt is more extensive than the Marble Hill belt but is unproductive. Although situated in Cherokee County, it is related geologically to the system of belts most highly developed in Pickens County and therefore demands brief treatment at this time. Beginning about 2 miles southeast of Nelson it curves southwestward to about 2 miles northwest of Canton. The rock, which is exposed in many places, is chiefly fine-grained and blue-gray, with a distinct schistosity due to mica flakes. The marbles are too impure for commercial use. A fourth small parallel exposure, known as the Sharp Mountain Creek belt, extends southwestward from about 1 mile north of Ball Ground.

The most productive marble quarries of Georgia are confined to a relatively small area near Tate and Marble Hill, in Pickens County. The

valley of Long Swamp Creek 1½ miles east of the railway station at Tate is nearly one half mile wide and is underlain with marble 6 to 8 feet beneath the soil. Evidently the unusual width of the deposit is due to truncation of an anticlinal fold, because the beds dip in opposite directions on the east and west sides. As indicated in figure 32, the removal of the top of such a fold by long erosion might provide a surface exposure (*a* to *b*) three or four times as wide as the actual thickness of the belt. The Creole and the Cherokee quarries are on the west limb of the fold, and the Etowah is on the east limb. These quarries are described later.

The remarkable attractiveness and uniformity of the marbles in Pickens County were recognized by early pioneers. The first systematic quarrying was done about 1840, and in 1842 a small mill with one gang saw was operated at Marble Hill. Nearly all the early production was for tombstones, which were hauled many miles by mules or oxen. With the advent of railways, markets were greatly expanded, and with an increasing use for marble in the construction field the industry became firmly established. The products of these great quarries and mills now reach every section of the country and are employed for memorials, for exterior and interior building, for numerous ornamental effects, and for sculpture. A notable example of the last use is the heroic figure of Abraham Lincoln carved by Daniel Chester French, and placed in that great American shrine, the Lincoln Memorial, in Washington, D. C. Reserve beds of marble which cover several square miles to a depth of at least 185 feet are practically inexhaustible.

Quarries that are now or have recently been active are described briefly in the following paragraphs. Geographically they fall in two groups—those of the Tate district and those of the Marble Hill district.

THE TATE QUARRIES.—Near Tate are two comparatively new quarries known as Silver Gray No. 1 and Silver Gray No. 2. The silver-tone grayish crystalline marble from these quarries is sold principally for monuments. Large quantities of dark blue and clouded marbles with a white background are produced at the Creole quarry also close to Tate. Color contrasts are sharp, and the stone is well-suited for matched panels and other interior decorative effects. Blocks of large size free from impurities and seams, are obtainable. The marble works easily and takes a good polish.

The Light Cherokee quarry, situated close to Silver Gray No. 1, is very large and deep. It furnishes several shades of light and dark gray coarsely crystallized translucent marbles, which are suitable for both interior and exterior use. The coloring matter is less pronounced and more uniformly distributed than in the Creole quarry. The Mezzotint quarry in the same group furnishes stone characterized by dark gray wavy veining on a light gray background. It is much used in interiors of buildings.

Marble from the Etowah quarry, within a few hundred yards of the Creole, is an outstanding type, for while it is of characteristic coarsely crystalline structure it is colored various delicate tints of pink (sometimes banded with white and with darker pinks) which are attributed to finely divided particles of hematite. It is adapted for both interior and exterior work and is often used as a trim in contrast with white marble, as well as for wainscoting and tiling.

THE MARBLE HILL QUARRIES.—The second important group of quarries is near Marble Hill 3 to 4 miles east and northeast of Tate. Most of them are in a narrow, high-walled valley, through which flows the east fork of Longswamp Creek. Many years ago one supplied marble for stair treads and tiling for the Georgia State Capitol. Geologists claim that the white marbles of this area have resulted from alteration of dark marble through contact metamorphism from an intrusive mass of hornblende. The marble is coarse-grained and translucent. Tremolite and muscovite appear in places and make polishing difficult. The Spring and the New York quarries, about 100 yards apart, furnish white and clouded marbles. Stone from the Rosepia quarry, which is not readily obtainable in large sizes, is fine-grained and therefore quite unlike the widely used Georgia types. It is pink, with brownish clouding, and is adapted primarily for interior use. White marble for building, interior decoration, and monumental purposes is provided by the Kennesaw quarry, which has been worked for many years and is very large. The Amicolola quarry is about 1 mile south of the New York. In this district joints are widely spaced and therefore blocks of large size are available. Much of the product is pure white. Tremolite, which occurs in small irregular blades, is the chief accessory mineral.

NORTHERN PICKENS COUNTY.—During recent years marble of monumental grade has been produced at Whitestone in northern Pickens County on the Godfrey property, as described by McCallie.[30] The best marble is coarse-grained and light to dark gray. Crushed and pulverized products are also sold.

STORAGE AND MANUFACTURE.—Much of the marble from the Tate and Marble Hill districts is manufactured into finished products in very extensive and well-equipped mills, most of which are operated by one large quarrying company, and others by manufacturing firms that have no quarries. There are marble-finishing mills at Tate, Marble Hill, Marietta, Canton, Nelson, and Ball Ground. A feature of interest in the quarry region is the operation of great overhead traveling cranes that convey marble blocks to storage piles. Acres of ground are covered with blocks waiting their turn for conveyance to mills. Railways provide transportation between quarries, storage yards, and mills.

[30] McCallie, S. W., Marbles of Georgia. Geol. Survey of Georgia Bull. 1, 1907, pp. 49–50.

Marbles Outside Pickens County.—Marble deposits have been noted in several counties outside the widely known Pickens County district, but few have attained commercial importance. Recent activity has been confined to a region about 2 miles southwest of Hollysprings in Cherokee County, where a quarry is operated for the production of green serpentine marble (verde antique). The rock occurs in a lenslike deposit about 600 feet long, with a maximum width of about 150 feet. Numerous veins intersecting the massive serpentine make it highly ornamental. They are of two kinds. A network of narrow veins, ranging from mere hair lines to one half inch in width and filled with dark green serpentine, is the most attractive feature of the rock. Larger and more persistent veins up to 5 inches in width are filled with dolomite and talc; these veins are sometimes open and cause much waste. As in most verde antique deposits quarrymen must contend with much unsoundness, but by cutting in accordance with joints, masses large enough for ornamental columns may be obtained. As waste is great and the rock can not be cut rapidly, quarrying is expensive, but on account of its highly ornamental character for baseboards, panels, columns, and pedestals the marble commands a higher price than white varieties. Two types are marketed, a rich dark green and a light green, both of which have attractive patterns.

Missouri.—In 1929, 477,010 cubic feet of block marble was produced in Missouri; it was valued at $927,530, or about 5.8 per cent of the value of total production for the United States. In 1930, production fell to 395,960 cubic feet, valued at $839,616; in 1931 to 216,730 cubic feet, valued at $553,291; and in 1937, to 180,860 cubic feet, valued at $445,114.

Carthage District.—The most important marble-producing center in Missouri is at Carthage, Jasper County. Geologically the rock belongs to the Burlington division of the Mississippian or Lower Carboniferous. It is a formation of wide extent in the State and in many places is quarried as limestone; in fact, the Carthage stone is sometimes described as limestone rather than marble. Buckley and Buehler,[31] in their detailed description of the district consistently speak of the rock as limestone. However, during the many years since this report was written the rock has become well-established as a commercial marble.

At Carthage the marble occurs in heavy, coarsely crystalline beds. It is white to light gray, with a bluish gray tint, although on a tooled surface it appears almost white. It is uniform in texture and color and has been recrystallized with little or no evidence of compression or distortion. In one respect it resembles Tennessee marble, for it is characterized by the presence of stylolites or suture joints parallel to the bedding and 2 to 20 inches apart. However, some of them are less desir-

[31] Buckley, E. R., and Buehler, H. A., The Quarrying Industry of Missouri. Missouri Bur. of Geol. and Mines, vol. 2, 2d ser., 1904, pp. 121–134.

able than in Tennessee, as they are inclined to weather more rapidly than the intervening rock. The highest quality of stone used as monument stock contains only the very finest of them. So-called "tar seams" containing bituminous matter cause waste in some quarries. Layers of flint nodules occur in places. The stone takes a good polish, is very strong, attractive, and enduring, and is used widely for both structural and monumental purposes.

Several quarries, mostly north of the city, have been opened, but during recent years production has been chiefly in the hands of one large company. Some stone is sawed and finished in the district, but much of it is shipped in rough blocks.

Phenix District.—The marble at Phenix, Greene County, is of the same geologic age as that at Carthage and resembles the rock from that place in many respects. It is coarsely crystalline and bluish gray and occurs in thick beds. Where free from chert or flint nodules, large, sound, practically flawless blocks of uniform texture may be quarried. Fortunately, the chert nodules are confined mostly to certain zones or layers. Suture joints or stylolites occur, as at Carthage; they are 2 to 14 inches apart and range from fine pencil-like markings to wavelike zones 3 inches in width; the larger ones are undesirable. In some beds the rock is quite fossiliferous, and the color is a little darker than that of the Carthage marble. A practically inexhaustible supply is available. A large mill is operated in connection with the quarry, and both mill and quarry are well-equipped with modern machinery. Both rough and finished stone is produced for exterior and interior construction.

South Greenfield District.—The Logan quarry at South Greenfield, Dade County, was in operation in 1929 and following years. According to report, the stone closely resembles Carthage marble.

Joplin District.—South of Joplin, Newton County, beds of the Mississippian formation similar to those described above are quarried for the production of interior and exterior marble. The best bed is 9 feet thick, coarse-grained and fossiliferous at the bottom and dense and compact near the top. It is uniform in texture and a pleasing gray. The suture joints are very tight and only slightly susceptible to weathering. Both rough and finished stone is marketed.

Ozora District.—Crystalline limestone that may be classed as marble occurs in eastern Ste. Genevieve County. Much of it is so intersected by cutters that large, sound blocks are difficult to obtain, on which account some operations have not been profitable. The most successful quarry is at Ozora. The beds worked are in the Kimswick formation, which lies geologically at a higher level than the Burlington, in which the other marble quarries of the State are located. A very attractive fossiliferous golden-vein marble sold in rough blocks for interior work has won a good reputation. The walls of the elevator lobbies in the Department of

Commerce Building in Washington, D. C., are good examples of its decorative value.

Alabama.—Building and monumental marble produced in Alabama in 1929 was reported as amounting to 52,900 cubic feet, valued at $381,781, or about 2.4 per cent of the value of the total production for the United States. Production was considerably higher in 1928. Production in 1930 was 99,790 cubic feet, valued at $481,186; in 1931, 46,390 cubic feet valued at $201,976; and in 1937, 57,050 cubic feet, valued at $313,663.

General Distribution.—The most important marbles of Alabama pass through southern Talladega and northern Coosa Counties in a continuous belt about 35 miles long, with a maximum width of 1½ miles near Sylacauga. They range in geologic age from Middle Cambrian to Middle Ordovician. On the southeast the belt is bordered by the Talladega slate or phyllite and for most of its length on the northwest by the Knox dolomite. Prouty[32] mentions several occurrences outside this belt which have not been worked commercially.

Characteristics of Marbles.—The marble beds are at least 200 feet thick in their best occurrences and usually dip about 30° southeast toward the slate. There is evidence of intense compression and folding; in consequence, definite systems of joints have been developed. A high percentage of waste is caused by the many irregular, radial, and closely spaced joints.

Alabama marbles are mostly white, and some beds provide pure, flawless material of statuary grade. They are a little finer-grained than the Vermont and much finer-grained than most of the Georgia marbles. Layers of light green talc and schist give ornamental patterns or clouding to some varieties. Some Alabama marbles are translucent. Porosity is low, averaging according to United States Bureau of Standards tests about 0.5 per cent, with a somewhat lower percentage in varieties best adapted for exterior use. The marble is notably pure, consisting of 98 to more than 99 per cent calcium carbonate. The products are widely known and are marketed in all parts of the country.

Productive Areas.—The most productive region is at Gantts Quarry about 2 miles southwest of Sylacauga, Talladega County, where very large open-pit and underground openings have been made. Diagonal jointing predominates. About 15 beds have been worked, each 4 to 11 feet thick. Because of differences in color and texture of the beds several standard types are produced. The quarry is well-equipped with the most modern machinery. In a completely furnished mill adjacent to the quarry the marble is manufactured into finished products, chiefly for use in building.

[32] Prouty, W. F., Preliminary Report on the Crystalline and Other Marbles of Alabama. Geol. Survey of Alabama Bull. 18, 1916, pp. 41–42.

A second large quarry is about three fourths mile northeast. For the most part, joint planes in this locality run with dip and strike, but occasional diagonal joints result in considerable waste. Some beds are clouded, and others are a very attractive cream white. Quarry blocks are shipped chiefly to New York, for manufacture into finished products.

Another quarry has been opened immediately northeast of that mentioned above. It is operated on the same beds and produces stone of the same general quality. High-quality marbles have been quarried at various other points on the belt.

Alabama marbles are used for exterior and interior building and decoration and for monuments. Some of the waste is sold in large fragments for use as riprap, and much of it is crushed for terrazzo, furnace flux, or other uses or ground to a fine powder and sold as whiting substitute.

New York.—Building and monumental marble produced in New York in 1929 reached a volume of 51,220 cubic feet, valued at $129,202, which represents about 0.8 per cent of the total production value for the United States. Production in 1930 was 68,350 cubic feet, valued at $161,214; in 1931, 22,770 cubic feet, valued at $56,059; and in 1936 9,890 cubic feet, valued at $57,774. Circumstances are somewhat peculiar in New York, in that more marble, in both quantity and value, is sold rough for riprap, stucco, terrazzo, cast stone, and crushed stone and as marble flour than as dimension stone. Present producing areas of block marble are confined to Clinton, St. Lawrence, and Dutchess Counties.

Clinton County.—The Chazy limestone near Plattsburg and Bluff Point is crystalline enough to take a good polish. Much of it is quite fossiliferous and furnishes variegated white, gray, and pink marbles suitable for interior use. A black marble deposit has been developed near Plattsburg.

St. Lawrence County.—A belt of pre-Cambrian marble occurs near Gouverneur. It is medium-textured, is mottled gray and white or solid blue-gray and takes a lustrous polish. Much of it contains 6 to 7 per cent magnesium and in a few places is almost pure dolomite. It is used for both building and monumental work. The main district is about 1 mile southeast of Gouverneur, where several quarries have been operated for many years. Much of the waste at dimension-stone quarries and the entire production of others are used as crushed stone for ballast, road construction, stucco, and cast stone.

Dutchess County.—The productive quarry area of Dutchess County is about 2 miles northeast of Wingdale. At least two large openings have been made, the rock dipping about 40° to the east in the south quarry and 50° to 60° west in the north quarry. They yield a uniform white dolomitic marble of fine, compact texture that has been in wide demand for archi-

tectural uses. At Wingdale a large, well-equipped marble-finishing mill is operated.

Other Quarry Districts.—Marbles have been produced at various other places in New York, among them the black marbles of Glens Falls, the verde antique of Port Henry, and the white marble of Tuckahoe. The last marble has been used quite extensively as building stone in New York City but is now used principally for chemical purposes and the manufacture of cast stone.

Massachusetts.—The volume of building and monumental marble produced in Massachusetts in 1929 was 19,720 cubic feet, valued at $97,910, or a little more than 0.5 per cent of the total production value in the United States. Production in 1936 was 9,110 cubic feet valued at $41,353.

The true marble areas of the State are confined to Berkshire County, where dolomitic marbles predominate. They are fine- to medium-grained and of uniform texture and shade from white to gray. Verde antique is quarried near Springfield, Hampden County.

Marbles of the Berkshire Hills have been quarried near Ashley Falls, West Stockbridge, and Lee, but during recent years activity has been confined to the last locality. Two types are produced at Lee—a clouded and a pure white. Tremolite crystals are present in places and cause some difficulty because they are harder than marble and on exposure tend to weather and leave a pitted surface. The stone polishes well and gives satisfactory service for interior and exterior construction and for monuments. A large marble-finishing mill is operated near the quarries.

In several places on and near Russel Mountain about 4 miles from Westfield, Hampden County, very attractive verde antique has been quarried. Two types of material occur—a 50-foot dike of serpentine, which is regarded as an alteration product of basic igneous rock, and a 75-foot bed of dolomitic marble impregnated with serpentine. Massive rock from the dike is of a rich dark green, variegated by bright green spots. A small finishing mill has been operated intermittently.

California.—In 1929 California produced 14,260 cubic feet of block marble valued at $71,259, or less than 0.5 per cent of the total production value for the country. In 1930, 15,740 cubic feet, valued at $50,640; in 1931, 15,390 cubic feet, valued at $46,399; and in 1932, 10,910 cubic feet, valued at $35,905, were reported. California marble is used almost entirely for interior decoration. Numerous deposits have been noted in at least 28 counties, but most of them are small or inaccessible, and in many places the rock is too shattered to permit quarrying large, sound blocks.

A fine-grained, hard, dolomitic marble is quarried near Lone Pine, Inyo County. The deposit is notable for its varied colors—yellow, black, and white, as well as white mottled with yellow, gray, and black.

Pink, yellow, and gray varieties occur at Columbia, Tuolumne County. The belt is 150 feet wide, and sound blocks of large size are easily obtainable. The numerous limestone deposits of San Bernardino County are nearly all crystalline enough to be classed as marble, but little recent production has been noted. A quarry near Volcano, Amador County, has been operated intermittently for many years for building and monumental marble.

Onyx marbles have been reported from several localities in California, but production has been small. A veinlike deposit at Suisun, Solano County, has been designated as onyx or travertine. The onyx deposits of California have been described by Aubury.[33]

Other Marble-producing States.—About 98 per cent of the total block marble produced in the country is obtained from the eight States already considered. The remaining 2 per cent originates in numerous centers that are small factors in present production, but some are interesting and promise much wider development in the future. They are described briefly by States or Territories in alphabetical order.

Alaska.—Numerous marble deposits in southeastern Alaska have been described by Burchard.[34] While several companies have operated in various places production has been confined chiefly to Tokeen on Marble Island and Calder on Prince of Wales Island. The Calder quarry is on a bluff about 100 feet above sea level. Metamorphism of the original limestone probably was caused by an intrusive granite which lies northeast of the marble. The belt is approximately 3,000 feet wide and at least 200 feet deep. Three types of marble are quarried—a pure white, which is the most valuable, a blue-veined white, and a light blue or mottled variety. The white marble is very pure, as analyses show more than 99 per cent calcium carbonate. Blocks are conveyed over an inclined railway to a wharf on deep water at Marble Cove.

At Tokeen a deposit about 2,500 feet wide and not far above water level includes white, blue-black, and various shades of gray marbles. They are medium- to fine-grained, take a good polish, and resemble some Italian varieties. Matched slabs having dark veins on a white background are much in demand for interior decoration. A high percentage of waste is occasioned by close and irregular joints.

All Alaska marbles are shipped by freight steamers to finishing mills on the Pacific coast, the largest being at Tacoma, Wash. To save freight only perfect blocks are shipped. Finished products are marketed chiefly throughout the Pacific Coast States.

[33] Aubury, Lewis E., The Structural and Industrial Materials of California. California State Min. Bur. Bull. 38, 1906, pp. 111–114.

[34] Burchard, E. F., Marble Resources of Southeastern Alaska. U. S. Geol. Survey Bull. 682, 1920, p. 118.

Arizona.—Onyx marbles are the only types produced in Arizona. The most extensively developed deposit consisting of bedded calcite and aragonite beautifully colored by iron oxides is at Mayer, Yavapai County, 15 miles southeast of Prescott. Highly ornamental products are obtainable from blocks having combined shades of white, green, and red. The deposit ranges in thickness from a few inches to 25 feet and covers an area of about 1 square mile. A finishing plant is at Dyersville, Iowa.

A second deposit is on Camp Creek west of Cave Creek, Maricopa County, about 52 miles north of Phoenix. It consists of boulders of calcite and aragonite in soft travertine. After conveyance to a mill at Phoenix the boulders are cemented together in a solid mass with plaster of paris and sawed into slabs and blocks for polishing.

Arkansas.—The best-known marbles of Arkansas occur northeast of Batesville, Independence County. The rock is classed by geologists as limestone, but it is recrystallized enough to take a good polish and is therefore classed commercially as marble. It consists of almost pure calcium carbonate occurring in the Boone chert series of lower Carboniferous Age. The rock is gray, of oolitic texture, and although more crystalline, resembles Bedford limestone. It occurs in beds 3 to 5 feet thick and being comparatively free from flaws or seams may be obtained in large, sound blocks suitable for exterior building. It has been used to a limited extent as monumental stone.

Black marbles of very good quality, occurring in the Fayetteville and Pitkin formations of Mississippian age, outcrop on the north slope of the Boston Mountain escarpment. Several quarries have been opened near Marshall and at other points west of Batesville, and the product is marketed as "Arkansas Black."

In 1929 a deposit in the Kimswick and Ferndale formations of Ordovician age was developed near Guion, Izard County, about 20 miles northwest of Batesville. The marble is coarsely crystallized and of a prevailing light gray; it occurs in approximately horizontal beds. Fair success has been attained in quarrying it with a wire saw.

A small amount of marble is produced at times near Cartney, Baxter County.

Colorado.—Marble has been quarried quite extensively on Yule Creek near Marble in northern Gunnison County, at a point about 10,000 feet above sea level and about 2,000 feet higher than the Crystal River Railroad. It occurs in massive beds at least 100 feet thick, with widely spaced joints which permit very large, sound blocks to be quarried. Pure white marbles almost of statuary grade are obtainable, as well as faintly clouded and golden-vein types that afford very attractive architectural effects. A large, well-equipped mill is operated at Marble. The industry is handicapped somewhat by difficult, costly transportation.

The Lincoln Memorial in Washington, D. C., is built mainly of marble from this quarry. The superstructure of the Tomb of the Unknown Soldier at Arlington also is of Colorado marble.

Maryland.—Although marbles occur in many localities in Maryland they have been actively quarried in only two districts during recent years. White marbles are quarried at Cockeysville, Baltimore County, and verde antique at Cardiff, Harford County. Years ago a highly ornamental conglomerate known as "Potomac marble" was quarried near Point of Rocks, Frederick County, but there has been no recent production.

The Cockeysville deposit about 15 miles north of Baltimore is of Ordovician age and consists of fine-grained, white, dolomitic marble of uniform texture. Pyrite crystals are quite common, but they are unusually stable, as evidenced by marble structures containing pyrite being exposed to the weather for over 100 years with no evidence of staining. Polished Cockeysville marble is of a dazzling whiteness quite noticeable in structures in many parts of Baltimore. Many monolithic columns have been manufactured for large buildings. The cheaper grades of this marble have been sold extensively for residential door steps, a characteristic feature of many houses in Baltimore. The stone has a good reputation and has been widely used for many years. A well-equipped finishing mill is operated in connection with the quarry.

A large serpentine area extends from the Susquehanna River near the Maryland-Pennsylvania boundary southwestward through Harford County into Baltimore County. Quarries have been worked in various places, but present production is confined to one large quarry at Cardiff. The rock is a very attractive, dark green, veined serpentine—a typical verde antique. Formerly the chief products were granules, terrazzo, stucco, and sand; and while these are still important, the principal output since 1920 is block marble, which is in demand by architects and builders. During recent years the operation has become increasingly extensive. The directions of the quarry walls have been altered in the lower part of the quarry to conform to the major joints, and waste has been reduced thereby. On account of a heavy overburden of defective rock underground drifting methods are pursued. Unsound blocks are manufactured into floor tile and baseboard in a mill at the quarry, and large, sound blocks are shipped to New York and other cities.

Michigan.—An attractive verde antique was quarried some years ago in a small way in Marquette County.

Montana.—Marble for interior building purposes, described as jet-black with a delicate gold vein, has been quarried near Townsend, Broadwater County. It is shipped in rough blocks. A vein of onyx marble 65 feet wide in Gallatin County, about 5 miles north of Manhattan, has been worked in a small way since 1930. A silicified, banded,

ornamental rock known as "Montana onyx" occurs near Virginia City, Madison County.

New Jersey.—A light green verde antique of attractive veining has been quarried about 2 miles from Phillipsburg, Warren County. Although the chief product is terrazzo, wider use of the stone in block form is in prospect.

North Carolina.—Commercial marble developments of North Carolina have been confined almost entirely to Cherokee County. The marble bed, extending across the county in a belt 1,000 feet to about a half mile wide, is a northward extension of the beds of Fannin County, Ga. It strikes northeast and dips about 50° southeast. The largest early operations were near Murphy and Regal, but recent production has been from a quarry near Marble. Two types of marble are obtained—a dark bluish gray, some of which is streaked and mottled with white, and a more or less uniform white stone. Close, irregular jointing at various intersecting angles has discouraged quarrying in this region, but the joints are more regular and more widely spaced near Marble than in other parts of the belt. A large marble-finishing plant has recently been built.

Pennsylvania.—A deposit of white marble in York County has been worked to a limited extent for local use. White marble was also quarried quite extensively in past years at King of Prussia, Montgomery County. Yellowish green serpentine from Chester County has been used for facing buildings, chiefly in and about Philadelphia and also in Washington, D. C. This stone weathers too rapidly for satisfactory exterior use and therefore has not been quarried for many years.

Puerto Rico.—A large, undeveloped deposit of gray marble with attractive dendritic markings consisting chiefly of manganese oxide occurs at the surface in the southern part of Puerto Rico. It takes a good polish and is available in large blocks.

Texas.—There is a deposit of attractive black marble near Marfa, Brewster County, which was developed to some extent in 1929.

Utah.—An interior building marble is produced in small quantity at Thistle, Utah County. On account of its unusual markings one variety is called "birdseye."

Virginia.—A black marble of good quality is quarried near Harrisonburg, Rockingham County. During recent years it has been used principally for terrazzo, but a mill for producing slabs was erected in 1933.

Washington.—Multicolored marble chips for terrazzo floors are produced in Stevens County.

QUARRY METHODS AND EQUIPMENT

Prospecting.—Marble is a recrystallized—that is, a metamorphosed—limestone. Metamorphism that converts limestone into marble is usually brought about by intense pressure and folding. Thus, the direction

and thickness of any bed may change abruptly, either laterally or vertically. On this account, marble beds are more uncertain in position and extent than flat-lying sandstones or limestones, and careful prospecting is essential to successful marble quarrying. It is extremely unwise to proceed with development work or with the extension of openings without reasonable assurance that an available mass of sound, attractive marble is sufficiently uniform in quality and abundant in supply for profitable exploitation.

Most marble beds outcrop in long, narrow bands which may extend many miles and represent truncated edges of folds in the rock; they may be curved or straight, depending upon the topography and the nature of the fold. A geologist may, by careful study of outcrops exposed here and there, obtain a knowledge of the chief structural features and thus determine the position, thickness, and attitude of beds with fair accuracy. Geologic maps of marble belts, if carefully made, have inestimable value to a prospector, for by consulting them he may determine the position of marble belts beneath the surface and know something of their extent and attitude.

Knowledge of exposed beds and their continuation beneath the surface is, however, insufficient. The nature and quality of the rock and extent of reserves can be determined definitely only by drilling. So much depends upon color, texture, uniformity, and general appearance that core drilling is necessary, for only by such means can solid samples be obtained at depth. As a rule, marble can be worked profitably only on a large scale, and a considerable outlay to determine whether conditions are favorable is regarded as a justifiable expense. Therefore, the larger marble companies do very extensive core drilling. The general principles of core drilling have been described in chapter IV, and the subject is presented at this time merely to emphasize its importance in view of the uncertain and variable character of most marble deposits.

Economic Conditions.—The success of a marble enterprise depends upon several important considerations quite distinct from the quality and extent of a deposit. A wise prospective marble producer gives careful consideration to market demands, prices, transportation facilities, competitive conditions, availability of labor, wage scale, and other economic questions for which a reasonably satisfactory answer should be obtained before large expenditures are made. Many enterprises have failed because these matters have not been fully studied.

Quarry Plan.—The chief factors which influence the plan of quarry operation are dip of the beds, depth of overburden, and uniformity of the product in the beds; these factors are intimately related. If desirable beds are thin and dip at steep angles, shallow quarries are worked along the outcrop, or underground mining is employed. However, thick beds dipping at steep angles may be worked in deep open pits, as at Knoxville,

Tenn. If the strata are flat and the desirable bed is near the surface, a wide, shallow quarry results.

As regards flat-lying uniform beds of great thickness, a heavy overburden tends to promote deep quarrying, whereas a light overburden will encourage the development of wider, shallower pits. If beds are vertical or steeply inclined a heavy overburden makes deep quarrying or tunneling almost obligatory, whereas if only light stripping is necessary greater lateral development is possible in the direction of the strike.

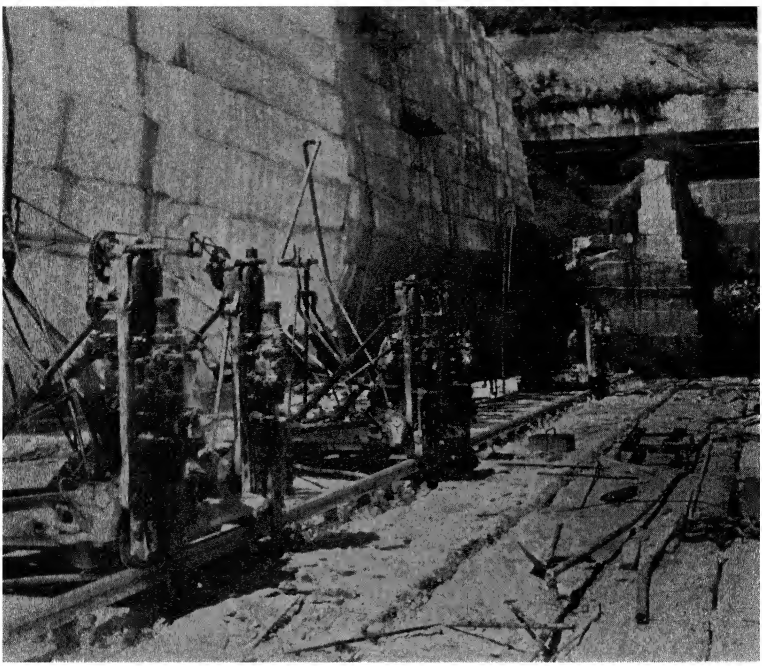

FIG. 33.—Method of channeling marble in Georgia. (*Courtesy of Georgia Marble Company.*)

Quarry plans may be influenced greatly by the quality of the deposit. For example, if the marble commands a high price, removal of a heavy overburden over an extended area may be fully justified, or underground methods might be employed. For a low-priced marble neither plan might be economically possible.

Channeling.—After a rock surface is cleared of all loose material by any of the stripping methods described in chapter IV the next step is to make primary cuts by means of which blocks are separated from solid beds. As the integrity of blocks must be preserved explosives are used sparingly. If the upper level of the rock is inferior through ages of weathering its removal as waste may be expedited by careful use of explosives; but where sound and serviceable rock is worked, very little, if any, explosive is employed.

Primary cuts are made almost universally with channeling machines, the general principles of which have been described in the chapter on limestone. Both steam and compressed-air machines are used in marble quarrying. The channeling process is illustrated in figure 33.

Sullivan, Ingersoll-Rand, Wardwell, Tysaman, and several other types of channeling machines are used, and each has its advocates. A favorite machine is the double-swivel channeler, which can be used for straight vertical cuts, for undercutting, or for cutting out corners. A few quarries in which operations are scattered over a wide area, and in which electricity is not used, employ machines with portable boilers attached. The "duplex" channeler consists of two machines on a single truck working in the same channel.

The electric-air channeler is self-contained, as all the mechanism is on the channeler truck. The air, compressed by a motor-driven "pulsator," is never exhausted into the open but simply driven back and forth under pressure in a closed circuit. The machine may be used for vertical, inclined, or horizontal channeling.

The chief factors to be considered in channeling are dip of the beds, soundness, and rift of the deposit. Where the rock is uniform, with no open bedding planes and no decided rift, channeling may be conducted on a level floor, a most desirable condition. However, if the beds are inclined it may be necessary to quarry each bed separately to maintain uniformity. The removal of right-angled blocks from successive dipping beds results in an uneven or saw tooth floor, which necessitates construction of an elevated track for the channeling machine. An improved method of quarrying on dipping beds is to place the channeling-machine track on the inclined rock surface in the direction of the dip. A balance weight overcomes the force of gravity which tends to pull the machine downhill.

The tendency of joints to occur in parallel systems has been pointed out. The importance of recognizing such systems and quarrying in accordance with them can scarcely be overestimated. A practical quarryman realizes that the prime object in marble quarrying is not to establish high records in rate of channeling or in gross production per man per month, irrespective of form or quality of the product, but rather to produce sound blocks of uniform quality. Cuts are, therefore, usually made perpendicular to or more rarely parallel to joints, and spaced to reduce to a minimum the number of joints in blocks. In many deposits one system is prominent, and cross joints are few. Under such conditions it is wise to channel in one direction only—at right angles to the chief system. Advantage may thus be taken of joints in making cross breaks. If joint systems permit, cuts are made at right angles to the direction of rift to take advantage of the direction of easy splitting in making cross breaks by drilling and wedging.

The rate of channeling varies greatly, depending on the hardness of the marble and convenience of operation. Where the machine works on an elevated track the daily average is low because so much time is lost in moving tracks. Recorded average rates range from 25 to 80 square feet a day for one machine.

Use of Wire Saws in Marble Quarries.—The construction and operation of wire saws are described in detail in a later chapter on slate. This method of cutting rather than channeling is followed in many European marble quarries but has been used to a very limited extent in cutting American marbles. Wire saws were employed about 1914, with favorable results, in a large quarry at Marble, Colo., and Weigel[35] has described their successful use in an Arkansas quarry during 1929. Companies in Vermont and Tennessee have tried them, with rather discouraging consequences. They are, however, used in trimming blocks in quarry yards as described later. There seems to be no valid reason why this equipment should not prove as successful in quarries as in yards, or should be less advantageous in American quarries than in those of Europe. No doubt problems that now confront American operators will be solved and wire saws will in time be recognized as standard equipment in quarrying marble as they are already recognized in the quarrying of slate.

Drilling.—A certain amount of channeling is regarded as necessary in most marble quarries. However, rock masses are separated by drilling and wedging wherever possible because they are ordinarily much less expensive than channeling. Drilling and wedging are almost invariably used for floor cuts.

The tripod, bar drill or quarry bar, gadder, and hammer drill are the chief types of drills employed. As the name implies, a tripod is a drill mounted on three iron legs. Its use is confined almost entirely to vertical holes, and it must be moved to a new position for each hole. The quarry bar has been described in the chapter on granite. It is used chiefly for vertical drilling, but a bar of adjustable height may also be used for projecting holes in horizontal rows in a bench face. A gadder is a bar held in vertical or inclined position, to which a drill is attached for making horizontal holes in the face, either in vertical or inclined rows. Two gadders are shown at the right in figure 36, page 215. The hammer drill, which has been described, has replaced to a great extent heavier types of drills in many marble quarries.

Drilling usually follows the direction of the rift or grain of the marble, thus taking advantage of the ease of splitting. The spacing of holes ranges from 4 inches to 2 feet, depending on the rift. Drill holes should be as small as possible without detracting from wedging efficiency; most hammer-drill holes are 1½ to 1¾ inches in diameter at the top.

[35] See bibliography at the end of this chapter.

If the rock is uniform and sound, lines of drill holes may be spaced regularly to give uniform, rectangular blocks. If unsound or lacking in uniformity of color or texture, adjustment of the spacing or direction of the lines of holes may be necessary to avoid waste and to grade the product properly. Making alternate holes shallow and intervening holes the full depth of the break desired is common practice. The depth of each hole is marked on the surface of the rock to guide workers in selecting wedges.

Wedging.—Wherever possible blocks should be separated by wedging, particularly where breaks are made to parallel the rift. To obtain a straight, uniform fracture proper wedges should be used, and they should be carefully driven. "Plug-and-feather" wedges, as previously described are universally employed.

A type of wedge that has proved highly successful is one of which the feathers are 3 feet long and the plug 3 feet 9 inches; the additional 9 inches is required for driving. The feathers are curved on one surface to fit the drill hole; the flat surface is perfectly straight and gives a uniform taper from one end to the other. The important feature is that, with the wedge in any position, the total diameter of feathers and wedge is the same at all points. Consequently, when the plug and feathers are inserted into the drill hole the inner side of each feather is in contact with the plug and the outer side with the wall of the drill hole throughout its entire length. Therefore, when the plug is driven the feathers are forced apart a uniform distance at every point. As a result the pressure exerted is distributed uniformly over their full length. Straight, even fractures are thus obtained with much lighter sledging than by any other method yet devised. In driving wedges it is important that the strain on all of them should be equal. A more uniform break will result by giving the rock sufficient time to fracture gradually, therefore wedging should never be unduly hastened, especially in marble that has no rift.

A pronounced rift is exceptionally advantageous in wedging, for it may allow comparatively wide spacing of holes and permit extending floor breaks to double the width of the ordinary marble block. Thus, a great saving is accomplished, for channel cuts may be made at intervals of 10 or 12 rather than 5 or 6 feet, and intermediate breaks may be made by drilling and wedging, which is a less costly method than channeling.

Usually rift parallels bedding; therefore, if the bedding dips at a steep angle, the rift may be inclined in like manner. If the rift is inclined and the quarry floor level, the direction in which drill holes are projected for floor breaks is exceedingly important. In a Colorado quarry where the floor is level and rift steeply inclined, channel cuts are made parallel to the strike of the rock. The influence of rift on the process of wedging under such conditions is shown in figure 34. When the row of key blocks has been removed and holes are drilled in the direction shown by arrow *a*

in the figure, the break made by wedging tends to leave the plane of the drill holes and slant upward on the rift, thus removing a corner of the block, as at *x*. When holes are drilled in the opposite direction, shown by the arrow *b*, if the channel cut is not continued lower than the plane of the drill holes, the break will be straight, as it will not run down below the bottom of the channel cut. It is apparent that, to avoid waste by broken corners and to reduce expense in drilling, the row of key blocks should be taken out as near as possible to the left side of the quarry, as shown in the figure, so that most of the drilling may be done in direction *b*.

Loosening Key Blocks.—In opening up a new floor the first blocks to be removed are known as "key blocks." Their removal is difficult because no face is available from which to work. If a band or mass of

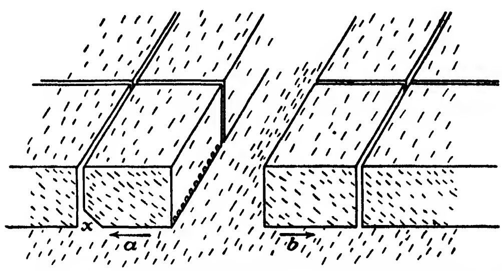

FIG. 34.—Diagram showing influence of rift on bottom breaks.

inferior rock traverses a quarry, key blocks may be located therein and removed readily by blasting into fragments but if key blocks consist of good marble they are usually preserved. After channels are cut on four sides the most difficult step is to make a floor break for the first block. A common method is to insert a slanting iron plate in the bottom of the channel cut and place the point of a wedge between it and the key block. When the wedge is driven the entire strain is exerted at the bottom of the block. A series of such wedges may be placed close together and sledged in succession. A horizontal rift greatly assists the process. After the first block has been removed, horizontal bottom holes may be drilled and the next block broken free by wedging.

Hoisting Out Key Blocks.—Any one of three methods may be used for hoisting out the first key block. The first is by use of the Lewis pin, which is adapted only to strong rock. A hole several inches deep is drilled at the center of the upper surface, and a bar with an eye in the top is placed in the hole with a wedge at each side of it. The bar is thicker at the bottom than at the top, so that when pulled upward it tends to tighten on the wedges, and the block may be lifted out with a derrick hoist. A second method, which may also be employed in strong rock is the use of grab hooks. Small pieces may have to be broken from the corners of adjoining blocks to make room for the hooks. If beds are weak

a third method is employed. Chain loops or cables are thrown over the block from opposite sides and drawn tight.

Subsequent Floor Breaks.—Removal of a row of key blocks provides a working face from which floor and vertical breaks may be made for subsequent removal of blocks. Floor breaks are usually made by drilling and wedging, though horizontal channel cuts may be made under certain conditions—for example, in driving tunnel headings. Where quarrying is conducted on a steeply slanting floor the wedging method would incur the danger of blocks sliding down upon the men the moment they were broken loose. To overcome this a single hole is drilled at the center of the floor line, and a light powder charge is exploded in it. The charge is so small that it makes the floor break without otherwise shattering the block.

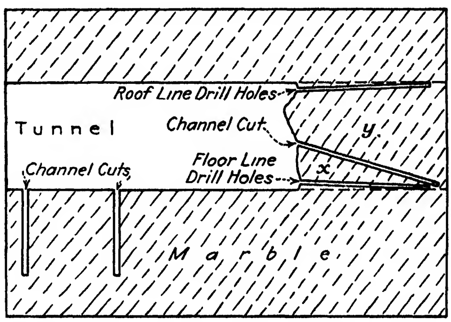

Fig. 35.—Diagram illustrating method of driving a tunnel in marble.

Underground Operations.—To follow steeply inclined beds without the heavy expense of excessive stripping may demand underground mining. Extracting marble blocks from drifts and tunnels is not uncommon; very extensive underground operations are conducted, particularly in Vermont. In underground work the most difficult step is to drive the preliminary opening at the roof. If the drift cuts across the beds open joints or seams are rarely available, and the heading must be driven in the solid rock without any assistance from rock structures. A common method of advancing a tunnel or drift is shown in figure 35. First a channel cut about 7 feet deep is made, beginning about 3 feet above the floor and slanting downward to meet the floor line. A row of horizontal holes is then drilled at the floor and another at the roof, the heading being 6 or 7 feet high. Horizontal holes are also drilled in vertical rows about 7 feet apart. The lower wedge-shaped mass of rock x in the figure is dislodged by blasting in the drill holes below the channel cut. Light charges of black blasting powder are used so that the marble beneath is not shattered. The upper overhanging ledge y is then broken down by discharging blasts in the holes above the channel cut. Broken rock is removed and the process repeated. If the heading is driven parallel

with the bedding an open seam may be utilized for roof or floor. A bed of soft schist or talc sometimes serves as a cushion to preserve underlying rock from the effects of blasting.

If a tunnel is driven in beds of high-grade marble the process may be modified to preserve the blocks. To provide space for removal of key blocks channel cuts must be made. Horizontal floor cuts may be made with a channeling machine, a slow process. Vertical cuts may be made with a reciprocating drill mounted on a rotating head. While operating it is rotated back and forth through a vertical arc, and thus it cuts a channel in much the same way as the circle-cutting drill described in the chapter on sandstone.

When a preliminary heading of sufficient width and length is obtained channeling machines or drills may be set up on the floor, and operation proceeds like that in an open quarry. As underground workings are enlarged pillars of marble 15 to 20 feet square are left for support at 50- to 80-foot intervals, depending upon the strength and stability of the roof.

In underground work certain complications are encountered which do not concern open-pit quarrymen. Artificial lighting and ventilation must be provided, and lateral haulage to open shafts becomes increasingly difficult. In some extensive workings in Vermont trackage is provided for hauling blocks through tunnels to hoist derricks at open quarries. Cable cars or electric trolleys may be used.

Undercutting.—The tunnel method may be modified by enlarging the quarry floor by an outward inclination of wall cuts. The process is simple, requiring no additional equipment and no expensive preliminary operation. A wide floor space is obtained with a minimum of stripping, and with moderate extension no supporting pillars are present to obstruct quarry operations. There are, however, certain disadvantages. In tunneling, the projection of a preliminary opening is costly and may produce only waste rock, but when once completed the subsequent channeling and drilling are carried on with almost the same facility as in an open quarry. In undercutting, however, every wall cut is slanting, and channeling at an angle is slow and relatively expensive. Moreover blocks of the outer row are angular, resulting in waste.

In extensive undercutting the danger from overhanging rock may be averted by leaving wing supports of marble at intervals. Undercutting is employed successfully in many Georgia and Vermont marble quarries. It is illustrated at the right in figure 36.

Hoisting.—As a step preparatory to hoisting, blocks usually are turned down by a gang of men with crowbars. The hoist cable may be attached by grab hooks, chains, or cable slings. Grab hooks are employed only when rock is hard and coherent. Two holes for the hooks are made on opposite sides of a block a few inches from the top. The mistake is some-

times made of drilling grab hook holes too deep, for the chief strain then comes not at the tips of the hooks but on the curved parts that are in contact with the upper edge of the block. Consequently, a corner of a block may chip off and allow the whole mass to fall. Holes should be deep enough to allow a firm grip of the rock, but the chief pressure should fall on the tip of the hook in the bottom of the hole. Also, the rock should be carefully balanced, as partial rotation may cause the hooks to slip. A safer method of attachment is to pass a chain completely

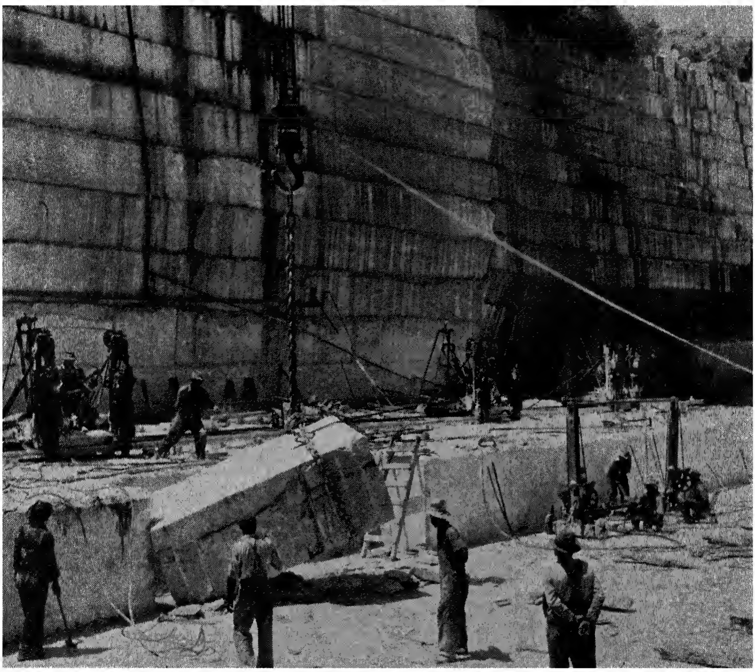

FIG. 36.—A marble quarry showing simultaneous hoisting, channeling and gadding operations. (*Courtesy of Georgia Marble Company.*)

around the block, as shown in figure 36. Another method of attachment is by means of a pair of cable slings, which are quickly handled and permit easy balancing.

Hoisting usually is done by powerful derricks. Masts and booms may be of wood or steel. Spliced wooden derricks having mast and boom, each in four pieces, are used in some regions. They are easy to transport and set up. Many derricks have a lifting capacity of 15 to 18 tons, but some are much larger. Derrick guys usually are supported by angle-steel bars set in concrete. The size of a derrick and choice of its location are governed by the position and inclination of beds and by the plan of development. Steam, compressed-air, or electric hoists may be used. Blocks are hoisted from the quarry and loaded on cars in one operation, if

possible; if a second step is necessary they are placed in a convenient position for future loading.

Scabbling.—The term "scabbling," as used by quarrymen, denotes the trimming of blocks to true rectangular form. Where a mill is close to a quarry this process may be omitted. If situated at a distance, or if the marble is to be sold in crude form, blocks are scabbled to avoid carrying waste material. The most common method is by manual labor with a scabbling pick. Hammer drills and wedges are used occasionally to remove the more prominent surface irregularities. In Tennessee a bar drill, mounted on a triangular plank frame resting on the surface of the block, is used to advantage. Drill holes are sunk in a row, and their position is guided by the inner edge of the plank base. By driving wedges in such drill holes an irregular surface is easily slabbed off. Wire saws are used successfully at some quarries. A number of blocks may be lined up and trimmed simultaneously with a single wire. Some operators regard this as the most economical method.

TRANSPORTATION

In some quarry regions mills are situated so favorably that short hauls only are required. In several eastern localities blocks are loaded by quarry derricks directly upon transfer cars. For distant haulage railroad cars and locomotives, electric trolley lines, and tractors are utilized. Cable cars may be required on steep grades. Teams and wagons were frequently used in past years, but the present tendency to consolidate companies into large units and the necessity for greater speed have led to more general use of rail transport.

EQUIPMENT AND OPERATION IN MILLS AND SHOPS

Most marble quarries of the United States have plants equipped more or less completely for sawing, polishing, carving, or otherwise preparing marble for structural and memorial uses. Also in many large cities mills are operated by independent companies.

Mill Location and Construction.—Mills operated by quarry companies may be close to quarries or in some near-by town. Water supply, power, and labor conditions are the chief factors that govern location. Laborers usually are better satisfied if mills are near towns where schools and other public institutions are more convenient and better equipped than in comparatively unsettled regions.

The most modern mills are fireproof, and many that are not have sprinkler systems. In most northern mills hot-air- or steam-heating systems are used.

Power.—Water, steam, and electricity are sources of power; the last is the most widely employed. Some large companies develop their own electric power, while others purchase it from power lines. One motor

may provide power for the entire mill, but it is usually advantageous to employ smaller units. For transmission from fly-wheel to countershaft pulley two types of belts are employed, a broad one of leather or fabric and a rope belt. The latter has the advantages of low first cost and of easy tightening, the pulley designed for this purpose being applied to a single turn of the rope. Direct water power is commonly transmitted by gears.

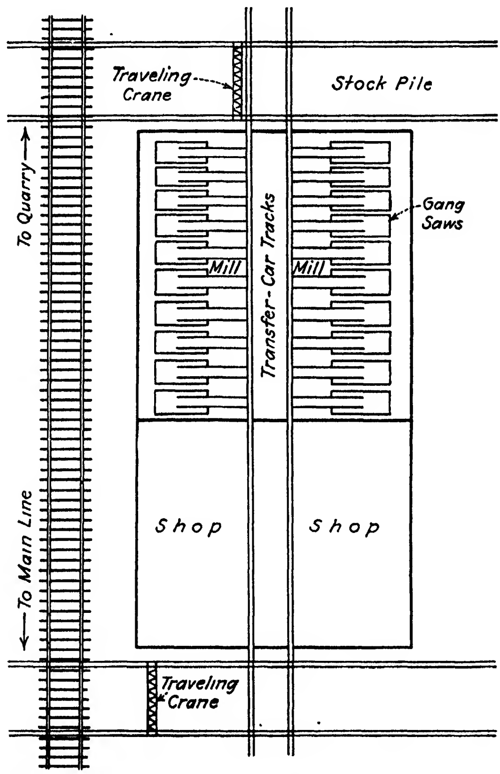

FIG. 37.—Convenient track arrangement for a marble mill.

Arrangement of Mill, Shop, and Yard.—The mill is that part of the finishing plant where gang sawing is done; all other finishing is classed as shop work. Stone is a heavy product, consequently the mill, shop, and yard usually are arranged to permit minimum handling.

Where both sawing and shop work are conducted the mill and shop are often placed 30 to 60 feet apart, with an overhead traveling crane between. A convenient arrangement for a large finishing mill is shown in figure 37. One traveling crane unloads blocks from cars on their arrival at the mill and either piles them or loads them on transfer cars. A track passes down the center with gangs on either side, and a small locomotive

crane spots transfer cars. Beyond the mill is the shop, and at the end of it another smaller traveling crane loads finished stock on railroad cars.

Sawing.—A first and very important step in milling is sawing the marble into slabs or rectangular blocks. The gang saws universally used are similar in construction and operation to those employed in sandstone and limestone mills, as described in preceding chapters. Silica sand is the abrasive used most commonly, though in some mills steel shot are employed, and greater speed in sawing is attained thereby.

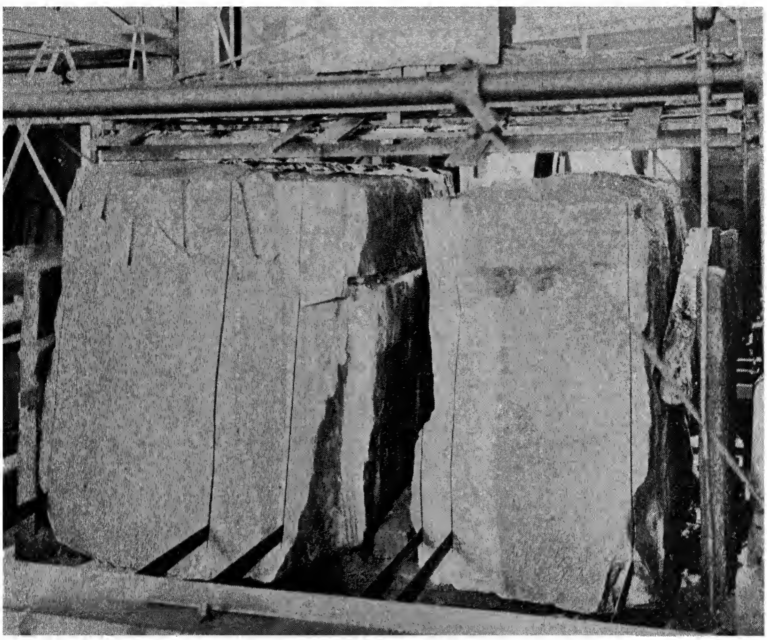

FIG. 38.—Gang saw in operation in a marble mill. (*Courtesy of Vermont Marble Company.*)

Shot are rarely used on marbles that are porous or contain soft veins, as steel particles may lodge and cause rusty stains or may interfere with later finishing processes. Slabs usually are sawed parallel to the grain, though sometimes distinctive markings are obtained by sawing crosswise. Great saving of material may be effected by sawing parallel with any joints that may be present in blocks. However, if cuts must parallel the grain it may be impossible to saw in accordance with the unsoundness. As a rule, unsound blocks can be sawed to better advantage into cubic stock than into thin slabs. The rate of sawing varies greatly, depending on the hardness of the marble. In stone of moderate hardness, the blades may sink at a rate of 1 to 2 inches an hour; in extremely hard marbles they may advance not more than 3 or 4 inches during an entire shift. Gang-saw operation is illustrated in figure 38.

Gang-car and transfer-car systems employed in marble mills are similar to those used in sandstone mills. Some large mills have more than 40 sawing machines and are equipped with every modern contrivance for handling materials. Sawed blocks and slabs are removed from cars by overhead cranes or derricks. Cubic stock may be handled with grab hooks or smooth-faced iron clamps which automatically close upon a block when under tension. Thin slabs may be removed in the same way or by cable slings.

Wire saws are used to a limited extent in place of gang saws. Several blocks may be lined up and sawed simultaneously. The operation requires little power or attention and gives satisfactory results in uniform material if slight variation in the thickness of slabs may be allowed.

Shop or Finishing Plant.—All finishing of marble after sawing is conducted in the shop. Where shops are operated in conjunction with mills they are usually so situated that sawed material can be transferred to them with the greatest facility. The shop may be a continuation of the mill, or the two buildings may be in parallel positions with a traveling crane between. Various shop operations are described in following paragraphs.

Coping and Jointing.—"Coping" and "jointing" are terms applied to the subdivision of marble slabs into baseboards, tile, or other finished products by means of Carborundum wheels or saws. In its strict sense coping is the process of cutting one slab into two without regard to the finish of edges. In jointing, however, the edges must be true and square with the face and without chipped corners. Carborundum wheels generally are employed for jointing because they usually leave so smooth a surface that edge rubbing is unnecessary. For this operation the wheel should project through the slab into a groove in the steel bed.

Rubbing.—Slabs and blocks cut to approximate size are squared and finished on a "rubbing bed," consisting of a horizontal circular bed of cast iron revolving at moderate speed. Most beds are driven from above by countershaft and gears, but some are geared underneath. Marble slabs or blocks held on the surface of the revolving disk to which sand and water are supplied are worn down to desired dimensions and smoothness. Carborundum beds are used to some extent for rubbing small pieces. Curved and irregular surfaces require hand rubbing with Carborundum bricks or with small pieces of marble supplied with sand and water.

Gritting and Buffing.—Gritting is a process which gives a smoother surface than rubbing. Emery powder is sometimes used as abrasive for this purpose. More frequently abrasive bricks are attached to revolving buffer heads which travel over the surface. The bricks are of silicon carbide or aluminum oxide, of varying degrees of fineness, depending upon the finish desired. Gritting produces what is known to the trade as a "hone" finish. For hand-gritting curved or irregular surfaces, natural

hone or pumice is used, though artificial abrasives are displacing them rapidly.

Buffing, the process which gives the final polish to marble, is accomplished by guiding over the wetted surface a buffer head of felt or other material of soft texture. "Putty powder," consisting of tin oxide or a mixture of tin oxide and oxalic acid, is used as abrasive. Chromium oxide—a green powder—is also used. Figure 39 shows a buffer or "Jenny Lind," as it is called in England. Various abrasive heads are

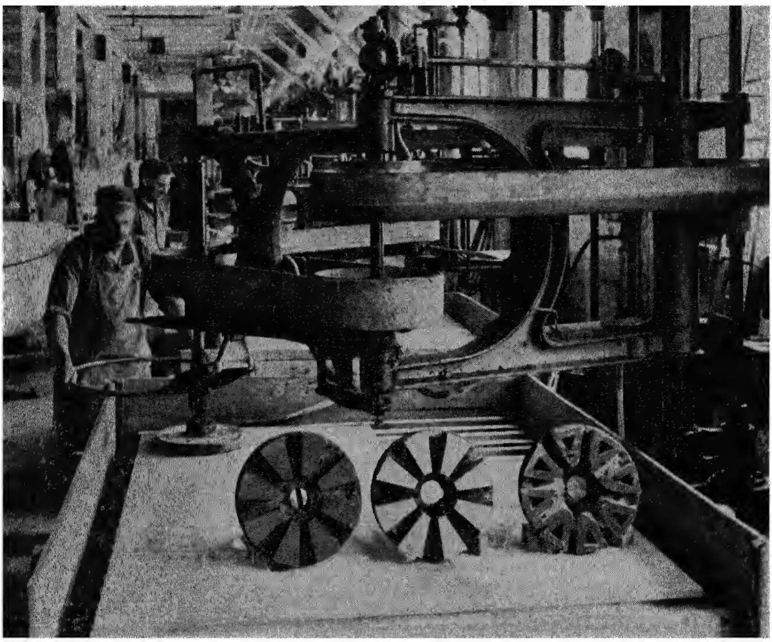

FIG. 39.—A buffer used for gritting and polishing marble surfaces. (*Courtesy of Vermont Marble Company.*)

shown in the foreground. Irregular surfaces are polished by hand with putty powder on a felt buffer or with a piece of fine sandstone or hone.

Shop Sawing.—Marble blocks are recut in the shop to various shapes and dimensions. A perforated circular saw, a diamond circular saw, or a single blade in a straight-cut gang frame may be employed. A perforated-steel circular saw employing sand or steel shot as abrasive cuts fairly well, but in many shops it is now replaced by the more rapidly cutting diamond saw. Circular diamond saws (see figure 40) are 20 to 72 inches in diameter. The first cost is high, but with care the cost of maintenance is not excessive. They occupy little space and saw rapidly. An abundance of water is necessary for successful operation, and care must be exercised to avoid overcrowding. Two diamond saws adjustable for width may be arranged to work simultaneously on the same shaft.

Planing.—Planers are used for cutting moldings and cornices. Usually the cutting tool is stationary, except for the lateral or vertical movements necessary for adjustment. The marble slab is carried on a traveling bed beneath the tool, which scrapes it to the desired thickness and to a shape governed by the contour of the tool. A great deal of this work is now done with Carborundum machines.

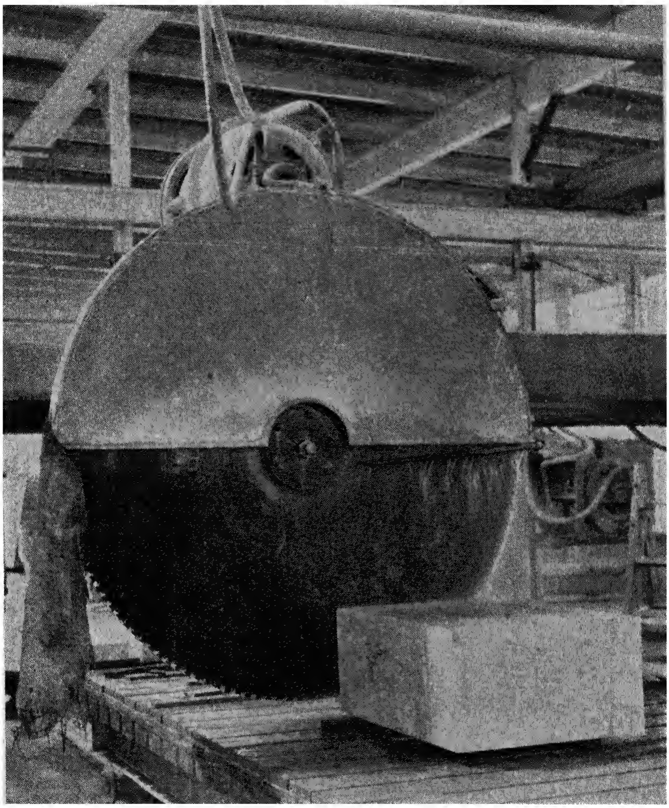

FIG. 40.—A diamond saw 6 feet in diameter equipped with 125 diamond teeth sawing a block of marble. (*Courtesy of Vermont Marble Company.*)

Machining with Carborundum Wheels.—Silicon carbide used as an abrading or grinding agent occupies an important place in all modern marble shops. Carborundum wheels run at high speed, and an abundant supply of water is directed upon the cutting edge. For straight slabs or blocks, cutting wheels of several types are in use. The smaller ones consist of solid Carborundum, or they may have steel centers. Large wheels are made of iron or steel and have inserted teeth. Other wheels have steel centers, with rims of silicon carbide which are thicker than the steel. They are used until the rim is worn down to the thickness of the

steel, then they may be rerimmed. Carborundum machines are capable of varied adaptations and can cut curved work, moldings, cornices, and balusters with great success. The wheel of the machine is a negative of the desired pattern. The marble block travels on the machine bed beneath the wheel, which cuts it to the desired shape; or it may be placed on a ball-bearing plate and held against the revolving wheel. In cutting balusters the marble and the Carborundum wheel are brought into contact while rotating in opposite directions. The peripheral velocity of the wheel is approximately 5,000 feet a minute, while the baluster rotates at about 100 revolutions a minute. In fluting or in making balusters it is advantageous to rough out marble to the general shape desired before working it with a wheel. If the wheel must remove considerable material the process is best divided into two operations. A 6 to 10 grit may be used for the roughing operation, which may remove stone to a depth of three fourths inch under favorable circumstances. For the finishing cut a 40-grit wheel usually is employed.

Cutting Columns.—Two principal methods are employed for cutting marble columns. A drum column-cutter is a circular steel drum which rotates on a vertical axis. Sand or steel shot may be used as the cutting agent, or the drum may have diamond teeth. The largest diamond-toothed drum column-cutter on record was used in cutting columns for the Lincoln Memorial in Washington, D. C. They are 7 feet 5 inches in diameter and were prepared in sections, each 58 inches long. The drum, which had 80 diamond teeth, completed a section in 4 to 5 hours.

Drum column-cutters give satisfaction for short columns or for short sections, as described above. For large monoliths a lathe must be employed. The marble generally is roughed out by hand to within one half inch of the finished diameter before being placed in the lathe. As the column rotates shaping is accomplished with a cutting tool similar to that used in ordinary machine lathes for turning metal shafts. Actuated by worm gear or other device, the tool travels slowly back and forth. For polishing plain columns a lathe may also be used, though fluted columns are rubbed or polished by hand.

Cutting and Carving.—All complicated patterns or other irregular designs must be cut by hand. Much of the straight and simple cornice and molding work formerly shaped with hand tools is now manufactured with planers or Carborundum machines. Hand carving may be done with hand tools and hammers but is accomplished much more rapidly with pneumatic tools.

Sand blasting is commonly used for lettering headstones. A shield with an opening the size and shape of the inscription area is placed over a monument. In early practice steel letters were glued on the surface of the rock in proper position, and a sand blast directed at high pressure against this surface for a few moments cut down the entire area except

that protected by the steel. A little hand trimming was necessary to correct irregularities caused by varying hardness of the stone. A more modern practice, employing a rubberlike "dope" instead of steel, has been described in the preceding chapter on granite. Much time is saved by the sand-blasting method, especially when many monuments of the same size and shape are manufactured.

Handling Material.—Overhead electric traveling cranes are widely used for handling heavy material. In many shops small stock is handled with great facility by means of small hand-operated trucks.

WASTE IN QUARRYING AND MANUFACTURE

Regardless of the high quality of any marble deposit there is always a certain percentage of loss, owing to processes involved in quarrying, trimming, and manufacture. Imperfections that are present in most deposits result in further waste. In fact, the final product may be much less than half the gross amount quarried. The problem of waste is therefore vitally important to every producer.

To minimize the heavy burden waste disposal places upon his industry the marble producer first directs attention toward all types of improved equipment and modern methods of excavation which tend to keep the proportion of waste to a minimum; he then seeks all possible outlets for marketing unavoidable waste. The first phase of the problem is prevention of waste; the second is utilization of waste.

Prevention of Waste.—The chief causes of waste are natural imperfections, such as joints, strain breaks, impurities, and lack of uniformity or attractiveness in color and texture. Systematic prospecting and development of the best beds in a deposit are important steps toward reducing waste. Making quarry walls parallel to major rock structures, such as joint systems, is equally important. When quarrying steeply inclined beds and maintaining a level floor it may be found desirable to separate blocks parallel to the bedding, to maintain uniformity in the quality of material in each block. When angular blocks are thus produced, much waste results if they are cut into cubic stock, as the corners must be thrown away; when cut into thin slabs waste may be much less. Various problems of this nature confront every marble producer.

The more common impurities in marble are silica, pyrite, and mica. These minerals tend to occur in definite zones or beds, the more impure of which may be separated and rejected by making cuts parallel to the bedding. If bands or streaks of undesirable minerals pass diagonally through blocks, waste may be excessive.

A condition of strain within a marble mass has in certain places caused so great a proportion of waste that workings have been abandoned. Usually the rock is under severe compressive stress in one direction only.

Quarrying relieves the stress at certain points, and consequent expansion may cause fracturing. Furthermore, expansion of one mass that is in rigid connection with the main mass still under compression may cause irregular or oblique fractures to form between the two masses. To overcome heavy losses from this cause attempts have been made to afford relief by uniform expansion of as large a mass as possible at once. To this end, a line of closely spaced, deep drill holes is projected along each side of the quarry parallel to the direction of compression, and a similar line across the quarry at right angles to the first line. The rock slowly expands, crushing the webs between the drill holes and closing the holes in the transverse row. Some benefit has resulted from the method, but the problem of overcoming strain breaks has not yet been satisfactorily solved.

Utilization of Waste.—Although the proportion of waste may be kept at a minimum by the adoption of economical quarry methods and use of efficient machinery, the unavoidable waste may still be large. Many manufacturers in various lines of industry have found that the fabrication and sale of byproducts from materials otherwise wasted have placed their industries on a profitable basis. Extensive waste heaps at many marble quarries testify to the need of greater development along the line of utilizing as well as avoiding waste. Marble producers are peculiarly fortunate, in view of the wide field of usefulness for their waste products. Many commercial marbles are pure calcium carbonate, the uses for which are very numerous. Some waste is now consumed for burning into lime, as crushed stone, as agricultural limestone, and in various other ways. The many potential uses are covered in detail in a later chapter on crushed and broken limestone.

MARKETING MARBLE

All high-grade marbles have a nationwide market range. Marketing is somewhat complex, because there are at least five types of agencies for this purpose. To the first group belong the so-called wholesalers, who sell marble to the trade chiefly in blocks or as sawed stock. The second consists of manufacturers who do not own quarries but buy marble blocks and finish them. Interior marble usually is both finished and set by them. A third group comprises dealers or contractors who have neither quarries nor mills but buy finished marble and sell it to customers, set in place. Producers who have quarries but no finishing mills or shops form the fourth agency. They sell their product in blocks to wholesalers or manufacturers. The fifth and largest group is composed of manufacturing producers who have quarries, mills, and shops, and engage in any and all activities of the trade. The merchandising of unfinished marble within the trade has no set rule or established general customs. A wholesaler sometimes sells rough blocks direct to owners

of buildings in which the marble is to be used, and the owners have the material sawed and finished.

Marble in the block and in sawed slabs more than 2 inches thick is sold by the cubic foot; slabs 2 inches thick and less are sold by the square foot. To be "merchantable" blocks usually must be at least 5 or 6 feet long, 3 or more feet wide, and 2 or more feet thick. In some localities a standard block is 7 by 5 by 4 feet, but great variations in size may occur. Measurements should as nearly as possible exclude surface irregularities. Contracts for finished marble in place are usually on a lump-sum basis. Much of the marble produced is sold on large contracts closed long before time of delivery.

Marble is classified as to kinds or varieties, and each kind often exhibits enough variation to require separation into two or more grades. Rare, beautiful marbles are high-priced but have a limited market; those agreeable in tone, texture, and finish and readily obtainable in large quantities bring a fair price and have a wide market.

IMPORTS AND EXPORTS

The following table compiled by the United States Bureau of Mines gives imports of marbles for consumption in this country during recent years:

MARBLE, BRECCIA, AND ONYX IMPORTED FOR CONSUMPTION IN THE UNITED STATES, 1924–1937, BY KINDS

Year	In blocks		Slabs or paving tile		All other manufactures	Mosaic cubes	Total value
	Cubic feet	Value	Superficial feet	Value	Value	Value	
1924	654,706	$1,279,351	309,999	$ 97,935	$205,353	$13,158	$1,595,797
1925	642,226	1,327,439	671,561	210,072	257,382	15,265	1,810,158
1926	864,895	1,789,570	403,458	222,230	438,712	7,028	2,457,540
1927	959,241	2,526,582	925,792	306,696	561,990	9,218	3,404,486
1928	586,069	1,673,363	845,464	310,785	483,071	6,126	2,473,345
1929	678,759	1,615,869	649,899	253,267	566,010	1,908	2,437,054
1930	718,233	1,581,839	591,616	254,179	329,279	12,157	2,177,454
1931	252,457	592,342	442,189	164,346	198,833	8,484	964,005
1932	153,828	319,088	232,264	71,832	64,724	54	455,698
1933	63,482	197,472	155,492	66,825	49,769	203	314,269
1934	19,046	126,320	76,184	27,961	32,222	239	186,742
1935	52,573	228,178	85,092	29,846	40,055	1,697	299,776
1936	60,956	257,634	150,364	58,979	43,879	140	360,632
1937	75,467	297,989	214,588	67,789	69,403	180	435,361

Exports of marble in block form are very much smaller than imports, averaging about 65,000 cubic feet a year.

TARIFF

The Tariff Act of 1930 provides a duty of 65 cents a cubic foot on marble in rough blocks and $1.00 a cubic foot if sawed or dressed and over 2 inches thick. Sawed slabs of various sizes and thicknesses carry duties of from 8 to 13 cents a superficial foot, with an additional charge of 3 cents if rubbed and 6 cents if polished. Manufactured articles, consisting chiefly or entirely of marble, carry a duty of 50 per cent ad valorem. The duties are essentially the same as under the Tariff Act of 1922.

PRICES

Marbles vary greatly in quality and therefore in price. The price range may be $1.50 to $7, or even more, a cubic foot. American marbles for exterior building purposes average about $2 a cubic foot in rough blocks. Prices of interior rough blocks at the quarry are quite variable, ranging from $2 to $7 and averaging about $2.40 a cubic foot. Monumental stock in rough blocks averages about $2 to $3 a cubic foot, though not much domestic marble is sold in this form. Verde antique in large, sound blocks of attractive color and capable of a fine polish commands prices of $6 to $8 a cubic foot at the quarry. Onyx marbles vary greatly in price, depending on appearance and size of blocks. The price may range from $5 to $15 a cubic foot.

French and Italian marbles sell in New York at $4.50 to $11.50 a cubic foot depending on quality. In 1931 second-quality Italian marble was selling at $4.75 to $5.75 a cubic foot. Belgian black marble has sold in New York at about $1.75 a cubic foot in rough blocks, though in 1929 and 1930 the price was much higher.

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CHAPTER X

SLATE

DEFINITION

Slate, like marble, belongs to the metamorphic group of rocks. According to the standard definition established by the American Society for Testing Materials, it is "a microgranular crystalline stone derived from argillaceous sediments by regional metamorphism and characterized by perfect cleavage entirely independent of original bedding, which cleavage has been induced by pressure within the earth." In simpler language, it may be defined as a fine-grained rock derived from clays and shales and possessing a cleavage that permits it to be split readily into thin, smooth sheets. The term includes materials differing widely in color and varying considerably in chemical and mineralogical composition.

ORIGIN

Except for certain rare varieties of igneous origin formed from volcanic ash or igneous dikes, slates have originated from sedimentary deposits consisting largely of clay. Minerals originally present with the clay in limited quantities include quartz; mica; feldspar; zircon; compounds of iron, lime, and magnesia; and carbonaceous matter, together with silicates other than those named. Through many centuries the clays carried by rivers were laid down as bedded deposits in deep water, and in later ages they may have been covered with beds of sand, gravel, or limestone. The pressure of such superimposed beds gradually consolidated the clays into deposits of shale, a laminated rock consisting essentially of clay but without the splitting properties of slate.

Many shales have been subjected to intense metamorphism and have thereby been altered into slates. The changes brought about by this process were both chemical and mechanical. The constituent minerals were transformed into new minerals, such as mica, quartz, chlorite, magnetite, graphite, tormaline, and various others, and the first three usually predominated. The mica and chlorite occur as microscopic flakes. The intense pressure tended to compress the rock and cause it to expand at right angles to the direction of pressure. The innumerable tiny flakes of mica and chlorite, formed as a result of metamorphism, assumed positions with their flat surfaces lying in the plane of flowage or elongation. Such parallelism of mineral grains resulted in that

tendency to split with ease in one direction which has been termed "slaty cleavage." As the rock usually is folded and contorted slaty cleavage may intersect bedding planes at various angles, a feature which distinguishes slate from shale, for the latter rock shows no tendency to split, except in a direction parallel to the bedding.

If the process of metamorphism is so incomplete that much of the clay remains unaltered the slate is termed "clay slate." When the process is carried farther and little or no clay remains the rock is called "mica slate." This type possesses greater strength, is denser and more resistant to absorption, and therefore more enduring than clay slate. It constitutes practically the entire supply of commercial slate in the United States. Continued intensive metamorphism of mica slate produces more complete recrystallization, forming coarser grains and developing in the rock a schistosity commonly wavy and irregular. Such highly metamorphosed rocks are known as "phyllites" or "mica schists."

MINERALOGICAL COMPOSITION

One of the most abundant minerals in mica slate is secondary muscovite, or white mica, commonly termed "sericite"—a hydrous silicate of potash and aluminum. It appears in very minute flakes whose outlines are recognizable only under a microscope with high magnification. Small grains of quartz also abound and are distributed regularly among the mica flakes. Usually considerable amounts of the micalike mineral chlorite are also present. Chlorites are of various kinds, the more common being hydrous silicates of aluminum and iron or magnesium. Clay, or kaolin, usually occurs only in small quantities in mica slates, though it may be quite abundant in clay slates. Minerals of minor importance are rutile, andalusite, hematite, pyrite, carbonaceous matter, graphite, feldspar, zircon, tourmaline, calcite, dolomite, and siderite; very small quantities of many other minerals are commonly identified. The general range of mineral composition is shown in the following table.

Mineral Composition of Average Slate

	Per cent
Mica (sericite)	38–40
Chlorite	6–18
Quartz	31–45
Hematite	3– 6
Rutile	1– 1½

CHEMICAL COMPOSITION

Results of many analyses indicate that clays, shales, and slates differ little in chemical composition, as the changes that occur during metamorphism are confined largely to rearrangement of chemical elements into new minerals and to changes in such physical characteristics as hardness and cleavage. Chemical composition, while of scientific

interest, has so little economic significance that detailed chemical analyses tell little or nothing of the true value of slates. Their commercial adaptability depends chiefly on mineralogical composition, structure, and texture. The range in composition of average slate, constituents of less importance being omitted, is as follows:

RANGE OF CHEMICAL COMPOSITION OF SLATE

	Per cent		Per cent
Silica	50–67	Soda	0.5–4
Alumina	11–23	Magnesia	0.5–5
Ferric oxide	0 5–7	Lime	0.3–5
Ferrous oxide	0.5–9	Water above 110°C	2.5–4
Potash	1.5–5.5		

PHYSICAL PROPERTIES

Color.—Slates are of various colors, the most common being light and dark gray, bluish gray, blue-black, red, green, purple, and mottled. Yellow, brown, and buff are occasionally found but as these colors usually have resulted from weathering, the slates are rarely of marketable quality. The color of a slate is determined by its chemical and mineralogical composition. Gray and bluish gray are due chiefly to the presence of carbonaceous material and other colors principally to iron compounds. Slates containing large proportions of finely divided carbonaceous matter are black. Permanence of color has considerable economic importance, for although some slates maintain their original colors for many years, others change to new shades within a comparatively short time. Such changes may be due to the presence of small quantities of iron-lime-magnesia carbonates, which decompose readily with the formation of the yellow hydrous iron oxide, limonite. Moderate, uniform fading may not be detrimental to appearance and may even produce a more pleasing effect. However, in replacing broken slates which are subject to color changes it may be difficult or impossible to match colors.

Green slates are of two types, the unfading and the fading, or "sea green." The former maintains a green color indefinitely; the latter when freshly quarried is greenish gray, which after a few years' exposure changes to brownish gray or buff. This change is not regarded as evidence of deterioration; it is, in fact, a weather-aging effect that many architects prefer. Circular and oval green spots occurring in certain New York and Vermont slates have long attracted attention. They are probably the result of chemical changes, such as reduction of iron oxide caused by decay of organisms.

Strength.—Slate, consisting as it does chiefly of very small overlapping flakes consolidated under pressure, is a strong rock. Tests are commonly made of compressive strength; elasticity; and modulus of rupture, or breaking strength. The last property, which is most significant for a majority of the uses to which slate is put, is determined by measuring the

breaking load applied at the middle of a bar of slate supported near the ends. The modulus of rupture of commercial slates is 7,000 to 12,000 pounds a square inch.

Porosity.—Most mica slates of good commercial quality are practically impervious to moisture, their porosity ranges from 0.02 to about 0.45 per cent. They are therefore well-adapted for sanitary uses.

Electrical Resistance.—Uniformly clear slate free from spots, veins, or iron-bearing minerals and low in carbon is highly resistant to electricity. Moisture increases its conductivity; hence after quarrying it usually is seasoned at least three months before use.

Durability.—High-grade slates, consisting essentially of stable silicate minerals, which are very resistant to weathering, are among the most durable building materials. However, to obtain the most enduring types careful selection must be made. Calcium carbonate apparently is the least desirable constituent of slates designed to resist long exposure, especially to sulphur fumes, for sulphur trioxide acting on calcium carbonate forms calcium sulphate, or gypsum, a mineral which expands greatly during crystallization with disruptive effects. Medium-grade slates are serviceable for 25 to 50 years, and the highest grades will far outlive most structures on which they are placed. Ferguson[36] has recorded that slate quarried near Delta, Pa., in 1734 was used for roofing seven buildings in succession. In 1930, the seventh building, a hog pen, was located near Delta. A sample of the slate has been rescued from this lowly use and is now on exhibit at the United States Bureau of Mines, Washington, D. C. After nearly 200 years in service it shows no evidence of deterioration. Even longer periods of use have been known in the Old World. A slate-roofed Saxon chapel standing in Bradford-on-Avon, Wiltshire, England, was built in the eighth century, and though moss-covered it is still in good condition after 1,200 years of constant exposure to climatic changes. Slate tombs high in the Alps near Oisans, France (which, from money and jewels found in them, archeologists have concluded were constructed about 500 B. C.), are still in good condition.

STRUCTURAL FEATURES

Bedding.—The shales from which slates originated were deposited primarily as clay beds. The beds of shale, at first horizontal, were tilted by subsequent earth movements, and the intense metamorphism that converted them into slates folded and contorted them. Differences in conditions of deposition often resulted in variations in color and texture of successive strata and such variations make possible tracing folds and contortions on a quarry wall. Bands representing beds of darker slate are known among quarrymen as "ribbons." In many

[36] Ferguson, E. G. W., Peach Bottom Slate Deposits, Pennsylvania. Min. World, vol. 33, 1910, p. 183.

deposits the original bedding has been so obliterated that it is extremely difficult to trace. Recognition of beds is important, for while the slate in any one bed tends to be uniform for considerable areas, it may differ greatly in successive beds. Therefore, for the proper development of a deposit of desirable slate the original bedding must be followed. Thus, in the Pen Argyl district of Pennsylvania quarries are situated on the "Albion vein," the "Diamond vein," the "United States vein," or the "Pennsylvania vein," each of which is of limited thickness. These so-called veins, or beds, are vertical or dip at steep angles, and their direction may change with depth. The folds (inclination) of beds have direct bearing on the location of quarry openings and on plan of development.

Slaty Cleavage.—Slaty cleavage is the structure which above all others differentiates slate from other rocks and gives it economic value. A true slate can be split into thin sheets with smooth, even surfaces. Some Pennsylvania slates can be split as thin as one thirty-second of an inch, but such sheets are too thin for practical use. In the manufacture of blackboard slates uniform, smooth slabs 4 by 6 feet or larger may be split readily to a thickness of three-eighths or one-half inch. In some deposits slaty cleavage is less pronounced than in others and the rock splits with greater difficulty.

Slaty cleavage may parallel beds, though commonly it intersects them at angles of 5 to 30° and may even cross them at right angles. Most slates split with the greatest ease when freshly quarried. Repeated freezing and thawing destroy the splitting quality.

Grain.—Although they split most readily in the direction of slaty cleavage, many slates have a second direction of splitting which, is less pronounced, but has economic significance. In slate literature this second direction is called the "grain," though quarrymen use the terms "sculp" or "scallop." It is approximately at right angles to slaty cleavage, usually nearly parallels the cleavage dip, and may commonly be recognized by lines or striations on the cleavage surface. It seems to result from mineral orientation, for many minerals lie so that their flat faces parallel the direction of the slaty cleavage and their long axes parallel the grain. In some deposits the grain is distinct, whereas in others there is practically none.

The relative ease with which slate splits in the direction of grain compared with the difficulty with which it breaks in any other vertical plane has distinct practical value in subdividing the larger blocks and reducing them to convenient sizes. In roofing slate the grain should always parallel the long sides, so that breakage, which is most likely to occur in the direction of grain, will parallel the dip of the roof.

Joints.—Joints, seams, or "headers" are more or less regular parallel systems of cracks, or fractures, in rocks, caused by pressure or movement.

The origin of joints in rocks has been covered in some detail in the chapter on granite. They may parallel the strike of beds or the direction of dip, or may run diagonally. There are also horizontal joints, sometimes termed "bottom" or "flat joints." In the Pennsylvania deposits curved, or undulating, joints have been noted. An open seam that parallels the bedding is termed a "loose ribbon."

Ribbons.—"Ribbons" are dark bands a fraction of an inch to several inches in width intersecting blocks of slate at various angles. They represent minor beds of somewhat different composition from the main body of rock. As they always parallel the bedding they serve as markers or indicators that assist in tracing folded or otherwise contorted beds. They are characteristic of the Lehigh and Northampton County, Pa. slates. The "soft-vein" ribbons in these slates usually are rich in carbonates and carbon and as a rule, disintegrate more readily than clear slate. Ribbon slate is therefore used for second- or lower-grade roofing and as structural slate. In "hard-vein" slate, however, most of the ribbons resist weathering, and this variety may be employed for high-grade roofing or other exterior uses.

IMPERFECTIONS

Curved or Irregular Cleavage.—Cleavage in other than a straight, even plane is undesirable in slate, though a small curvature is permissible for small roofing slate. Blackboards and structural slate products are subdivided by splitting, and a crooked split necessitates much labor to reduce the slab to an even plane. A block of slate having curved cleavage may produce only three slabs of a given thickness, whereas a straight-splitting block of the same thickness may produce five or six similar slabs.

Slip or False Cleavage.—Slip cleavage is a tendency to split along incipient joint planes or seams. It usually runs diagonal to the slaty cleavage, causing waste.

Veins.—Veins are common in slate quarries. They may follow bedding or cleavage planes, intersect them at various angles, or be very irregular. Veins of quartz are termed "flints" by quarrymen. Calcite or "spar" veins are common, as are also those filled with a mixture of quartz, calcite, dolomite, and possibly chlorite and biotite.

Impurities.—One of the most undesirable impurities in some slates, is calcium, usually in carbonate form. Its harmful effects have been mentioned under "Durability." Iron carbonate is sometimes present, and its decomposition not only weakens the slate, but the resulting iron oxides may cause stains. Iron sulphides may oxidize and form spots and stains. The stability of the iron sulphides has been discussed in some detail in the chapter on marble. The oxidation of iron-bearing minerals, especially ferrous carbonate, often causes color changes. Nodules of flint or quartz encountered in some slates greatly increase the

difficulty of working. Carbon usually is regarded as an agent of disintegration and is particularly undesirable in electrical slate, as it acts as a conductor and promotes leakage of current.

USES

Roofing.—In early years roofing was, with minor exceptions, the only use for slate, and it is still a very important one. Slate is durable, attractive, noninflammable, and adaptable to the most artistic architectural effects. There are two grades of roofing slates—standard and the so-called architectural. Material for standard slates should have straight, uniform, smooth cleavage, and the color should be permanent, or if it is subject to change, uniform color aging without deterioration is usually demanded. In the United States standard slates are sold by the "square"—enough slate to cover 100 square feet of sloping-roof surface with a 3-inch head lap. In France and England the unit is a "mille," consisting of 1,200 slates of any given size and 60 additional to cover loss by breakage. Standard slates range in size from 6 by 10 to 4 by 24 inches, and in thickness from three-sixteenths to one-fourth inch. The number of slates required for a square ranges from 85 to 686, according to size. The weight of a square of average standard roofing slate is about 650 pounds.

Architectural grades have attained prominence during the past 10 years. They meet the demand of modern architecture for rough, rugged building materials rather than for the smooth, mathematically exact types formerly popular. Architectural slates may be 1 to 2½ inches thick and 2 to 4 feet long. Surfaces may be rough and uneven and colors variable. For large structures the heavier slates are placed near the eaves with the smaller and thinner ones toward the ridge. Slates thus graduated in size and of a variety of blending colors produce very beautiful architectural effects. Slate slabs set in mastic are also used extensively for flat roofs, roof promenades, and terraces.

Mill Stock.—While roofing was originally the dominant branch of the slate industry many other uses have developed. Slate worked up into slabs of various sizes and shapes is classed as "mill stock." The different products are described in following paragraphs.

Blackboards and School Slates.—Slate suitable for blackboards and bulletin boards must be soft, and also of uniform color and texture. Such material is obtained chiefly from what is known as the "soft-vein" region of Lehigh and Northampton Counties, Pa. The soft vein is the northern slate belt, which includes the region in and about Bangor, East Bangor, Pen Argyl, Danielsville, Slatington, and Slatedale. This comparatively small area, about 30 miles long, provides most of the world's production of blackboard slate. Because of their smoothness,

uniformity, permanence, and attractiveness, slate blackboards are superior to all other types now in use.

School slates were once commonly used in America, but demand for them has greatly declined. Foreign demand is considerable, and most of those now manufactured are exported. As school slates are small their manufacture permits utilization of the smaller pieces of slate, many of which otherwise would be wasted. Slate for this purpose is similar to that used for blackboards, and deposits are confined largely to the same area.

Structural Slate.—Although roofing slate ordinarily is regarded as structural material, a distinction is made in the slate industry, the term "structural slate" being employed for products used chiefly for interior structural and sanitary purposes. The chief products are mantels, floor tiles, steps, risers, flagging, skirting or baseboard, window sills, lavatory slabs, billiard and other table tops, wainscoting, hearths, well caps, vats, sinks, laundry tubs, grave vaults, sanitary ware, refrigerator shelves, flour bins, and dough troughs. Soft, even-grained slate, preferably not highly fissile, is required for such purposes.

Floors and Walks.—Slate is being used in increasing quantities for ornamental flagging in sidewalks, porches, and sun parlors. Some is honed and fitted for close joints, but much is used with split or "quarry cleft" surface and in irregular outline, which permits utilization of much slate that heretofore has been discarded as waste.

Electrical Slate.—Certain types of slate have very high dielectric strength and on this account are suitable for electric panels and switchboards. Their superior qualities are strength, rigidity, toughness, and easy workability. Also, they can be matched easily when switchboards are enlarged. Electrical slate should be low in magnetite, carbon, and other low-resistance minerals and capable of being cut and drilled easily without scaling.

Granules and Flour.—Slate crushed to granular form is employed widely in the manufacture of slate-surfaced composition roofing. Red, green, blue-black, and gray granules are manufactured from slates having these natural colors. Granules are also artificially colored to provide materials for the highly colored roofs demanded by many architects and home builders. Ground slate is used for surfacing tennis courts and other playgrounds. Pulverized slate, known as "slate flour," is used as a filler in paints, road asphalt-surface mixtures, roofing mastic, and various other products.

HISTORY OF INDUSTRY

European History.—One of the earliest references regarding the use of slate concerns a slate-roofed chapel at Bradford-on-Avon, England, built in the eighth century. In the twelfth century thick, rough Welsh

slates were used. However, it was not until the latter part of the eighteenth century that the slate industry attained importance, and even then methods were crude and wasteful. After 1850, with the development of foreign trade and extension of railways the Welsh slate industry grew rapidly. In France the industry made rapid progress about the same period.

History in America.—The oldest slate quarry on record in America was opened near Delta, Pa., in 1734. The first quarry in Virginia was opened about 1787 to provide slate for the roof of the State Capitol, and in Georgia the first production was in 1850. From these early beginnings slate quarrying spread to eastern Pennsylvania, New York, Vermont, and Maine, and between 1870 and 1880 it became a well-established industry. Welsh slate workers were the originators of the industry in several districts.

Although production has assumed fair magnitude it has not increased proportionally with building construction. This is singular in view of the adaptability and permanence of slate and the satisfactory service afforded in its many applications.

Reasons for Slow Growth.—As may be noted from the table on the following page, which shows production over a period of years, the industry grew rapidly during 1923, and maintained its increased volume from 1924 to 1926. In the three following years, which were generally prosperous, there was decided recession. Lack of sustained activity is due to various causes. It is to be attributed chiefly to the keen competition that slate must meet in every line of production—a condition covered more completely in the section on marketing. Other reasons for slow growth are excessive waste and high cost of quarrying and manufacture. These difficulties are being overcome measurably, as will be shown later.

GENERAL DISTRIBUTION

The active slate-producing districts of the United States are the Monson district, Me.; the New York-Vermont district, including Washington County, N. Y., and Rutland County, Vt.; the Lehigh district, including Lehigh and Northampton Counties, Pa., and Sussex County, N. J.; the Peach Bottom district, including Lancaster and York Counties, Pa., and Harford County, Md.; and the Buckingham County (Arvonia) and Albemarle County districts of Virginia. The geographic locations of these areas are shown in figure 41. These districts produce roofing slate, and some of them also produce mill stock, roofing granules, and slate flour. Roofing granules, flour, and some other products have also been manufactured during recent years in California, Georgia, Tennessee, and Utah.

PRODUCTION

The following table prepared by the United States Bureau of Mines shows sales of slate, by uses, from 1926 to 1937. The total quantity and value given for each use are the totals of the reports of quarrymen (not

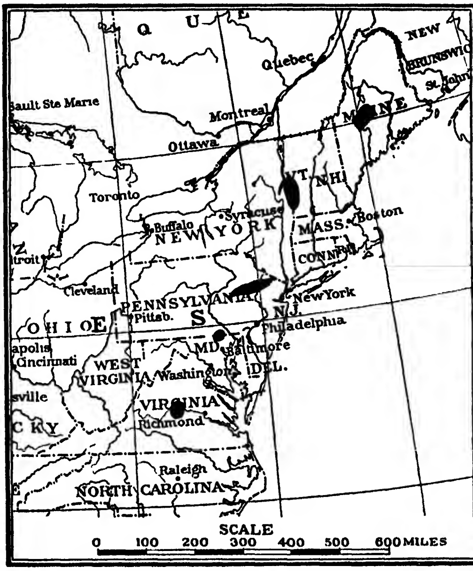

FIG. 41.—Map showing principal slate-producing areas in the United States. (*Prepared by H. Herbert Hughes.*)

selling agents), and the value is that f.o.b. quarry or nearest point of shipment.

SLATE (OTHER THAN GRANULES AND FLOUR) SOLD BY PRODUCERS IN THE UNITED STATES, 1926–1937, BY USES

Year	Roofing slate		Mill stock		Other uses* (value)	Total	
	Squares (100 square feet)	Value	Square feet	Value		Short tons (approximate)	Value
1926	465,900	$5,079,087	10,278,130	$4,191,185	$ 73,127	219,950	$9,343,399
1927	468,560	4,949,940	9,287,680	3,519,386	135,448	232,280	8,604,774
1928	483,280	5,411,332	9,220,170	3,408,304	184,184	232,380	9,003,820
1929	462,120	4,920,766	9,936,480	3,702,145	124,524	241,130	8,747,435
1930	340,140	3,359,939	7,917,220	2,755,530	100,732	173,910	6,216,201
1931	277,700	2,364,861	5,794,380	1,754,054	66,904	138,440	4,185,819
1932	144,410	1,072,255	2,840,020	810,443	23,786	74,490	1,906,484
1933	153,170	967,834	2,089,650	519,078	28,951	73,240	1,515,863
1934	137,010	1,033,164	2,113,620	581,959	26,705	66,570	1,641,828
1935	221,630	1,456,041	2,994,470	849,796	35,333	103,690	2,341,170
1936	366,130	2,607,402	4,108,450	1,175,668	55,358	165,110	3,838,428
1937	365,800	2,728,109	4,194,160	1,225,645	73,554	167,550	4,027,308

* Includes flagstones, walkways, stepping stones, and miscellaneous slate.

The following table shows distribution of production by States. The amounts vary from year to year, but the relative production of the States is fairly constant. The 1929 figures are shown because they are probably more typical than those for later years.

SLATE SOLD BY PRODUCERS IN THE UNITED STATES, 1929, BY STATES AND USES

State	Operators	Roofing		Mill stock		Other uses (value)	Total value
		Squares (100 square feet)	Value	Square feet	Value		
1929							
Arkansas	1	....	....	....	....	*	*
California	2	....	....	....	....	*	*
Georgia	1	....	....	....	....	*	*
Maine	2	3,720	$ 38,316	702,740	$ 613,996	$ 1,315	$ 653,627
Maryland	3	*	*	....	....	*	214,770
New Jersey	1	*	*	....	....	....	*
New York	22	14,670	204,362	....	....	634,169	838,531
Pennsylvania	38	251,880	1,967,428	8,011,080	2,473,838	356,934	4,798,200
Vermont	51	151,810	2,214,869	1,222,660	614,311	875,714	3,704,894
Virginia	6	35.460	434,628	....	....	*	*
Undistributed†	...	4,580	61,163	....	....	754,135	1,035,156
	127	462,120	$4,920,766	9,936,480	$3,702,145	$2,622,267	$11,245,178

* Included under "Undistributed."
† Includes output of States entered as (*) above.

INDUSTRY BY STATES[37]

Because of the unusual conditions prevailing in 1930, 1931, and 1932, it is deemed advisable to use 1929 figures to indicate the relative standing of the various States.

Maine.—Sales of slate in Maine in 1929 were valued at $653,627, or about 5.8 per cent of the total production-value for the United States. Production in 1930 was valued at $506,322, in 1931 at $257,619; and in 1937 at $388,521. During recent years two large companies have furnished most of the supply, though others have produced at times.

The slate region of Maine lies in about the center of the State in southern Piscataquis County near Monson, Blanchard, and Brownsville. Slate occurs in a belt 15 to 20 miles wide, and the commercial beds lie south of the central granite area. The strike is in general northeast, and the dip is very steep, ranging from 80° to vertical. The general structure is obscure.

Monson District.—Production in Maine is confined almost exclusively to the vicinity of Monson. The commercial beds are of very fine-grained,

[37] The geology of the various slate districts is based mainly on U. S. Geol. Survey Bull. 586, Slate in the United States, by T. Nelson Dale.

dense, uniform, blue-black slate. The slaty cleavage is vertical and therefore practically parallels the bedding. Originally open-pit methods were used, but recent production has been principally from underground workings.

The largest pit, known as the old Pond quarry, is 500 feet long, 100 feet wide, and 250 to 400 feet deep. This opening intersects about 15 beds of slate interbedded with dark gray or black quartzite. The structure of the slate does not favor open-pit working, chiefly on account of the vertical cleavage, which weakens the walls. Obviously, water entering vertical cleavage planes and freezing therein will cause walls to spall. Furthermore, rock with vertical cleavage is less capable of sustaining weight than flat-lying masses and will bulge inward and finally collapse under intense pressure. On this account, operations in recent years have been confined to certain thick beds of high quality, and underground methods have been followed. Details of the method are given in the section dealing with technology.

Workings adjoining the old Pond quarry have been conducted chiefly on one bed 9 feet thick dipping at about 10° from vertical. The cleavage is vertical and nearly parallels the strike of the beds, the angle of intersection ranging from 5 to 10°. The grain is vertical and perpendicular to the cleavage. The 9-foot bed and other parallel beds have been quarried extensively near the Pond quarry and at other points over a distance of 3 miles to the northwest.

Another series of openings is or has been worked about 1 mile south of Monson village. The chief bed worked is 10 feet thick, stands vertical, and strikes N.63°E. The cleavage is vertical and nearly parallels the strike. The grain is vertical and at right angles to the cleavage. For many years slate was removed from long, narrow, vertical openings, but the difficulty of maintaining safe walls at depths of 300 to 350 feet was so great, especially in view of the inclined open joints occurring frequently throughout the district, that underground stoping methods were adopted and have been employed with success.

Various other openings have been made near Monson, and the general structure is similar in all deposits. Narrow, vertical beds with vertical cleavage are the most notable characteristics.

Monson slate is especially adaptable for the manufacture of switchboards, panels, and other electrical insulators. Not only has it exceptionally high dielectric strength, but it is easily cut and drilled, and the uniform ebonylike surface is attractive. A large percentage of the total production in this district is electrical slate, though some blackboards and a limited quantity of sanitary and structural slate are also manufactured. Roofing-slate production has always been small, but this branch of the industry is attaining greater importance.

Large, well-equipped finishing mills are maintained in the Monson district. Electrically driven machinery of the most modern type is employed to saw, plane, rub, polish, and drill slabs of slate with the utmost accuracy and precision. Monson slate has won an excellent reputation for both quality and workmanship. The product is transported by a narrow-gage railway 6 miles long, connecting with the Bangor and Aroostook Railroad. Winter weather is severe, and difficulty is experienced at times from the heavy snowfall.

North Blanchard District.—Many years ago two large quarries were operated at North Blanchard about 6 miles west of Monson for production of electrical, structural, and roofing slate, but no activity has been reported during recent years. A series of alternating beds of dark gray slate and quartzite having a total thickness of 50 to 65 feet strikes N.25° to 37°E., and dips about 80°. The slaty cleavage parallels both dip and strike and is at right angles to the grain, which is vertical. The best beds are 4 to 7 feet thick. The quarries are near the railroad.

Brownsville District.—A dark gray slate was quarried many years ago in southeastern Piscataquis County near Brownsville. Numerous slate beds over an area more than 160 feet wide are interbedded with quartzites, as in the other districts. The best beds are 6 to 9 feet thick, run northeast, and dip about 75°. The cleavage approximately parallels bedding. Roofing slate was the chief product, but no production has been reported from this district since about 1914.

New York-Vermont. *General Features.*—An important slate district extends from Rutland County west-central Vermont into Washington County, New York. Slate production in Vermont in 1929 was valued at $3,704,894, or about 33 per cent of the value of total production for the entire country. Production in 1930 was valued at $2,463,241, in 1931 at $1,508,518, and in 1937 at $1,431,798. Roofing slate is the chief product, but material for floors, walks, mill stock, granules, and slate flour is also produced in large quantities. Production in New York in 1929 was valued at $838,531, or about 7.5 per cent of the value of total production for the United States. In 1930 it was valued at $438,619, in 1931 at $325,476, and in 1937 at $360,064. Granules and slate flour constitute about three fourths of the production, and roofing slate one fourth.

Geology.—As the area embraced is a continuous geologic unit, it is discussed as a whole. The geology of the district is complex. The slates are of two ages—those of Ordovician age including red, bright green, and black slates and those of Cambrian age including green, purple, and variegated slates. In some places the Cambrian rocks protrude through the Ordovician, and intense folding and faulting make the relationships obscure. The slate beds lie in close folds more or less overturned to the west with eastward-dipping slaty cleavage. Most of

the Cambrian roofing-slate quarries are close to the boundary between the Cambrian and Ordovician. In general, the slaty cleavage dips eastward 30 to 50° and either parallels the beds or crosses them at a low angle. The grain or sculp is usually vertical but variable in direction in different quarries. Close jointing in the dip direction occurs in places. Quartz veins, pyrite crystals, and dikes appear in some areas.

Varieties and Uses.—The various types of slate with their distribution and uses are described in following paragraphs.

Sea-green Slate.—The term "sea-green" is applied to a variety of slate that when first quarried is light gray to slightly greenish gray, but which after a few years' exposure changes to a buff or brownish gray. This color-aging is preferred by some architects and builders. As both the sea-green and unfading green slates are of Cambrian age and evidently belong to the same period of deposition it is difficult to find a reason for the difference in degree of permanence in color. Generally, the sea-green slates are found in the region south of a point about 2 miles north of Poultney, and the unfading green slates north of that point, but exceptionally the occurrences are reversed. The difference probably is due to a change in sedimentation, the southern area having more carbonate and the northern less carbonate and more chlorite and pyrite. Some of the sea-green slates are classed as hard, others as soft. They are used chiefly for roofing and to a small but increasing extent for floors and walks.

Unfading-green Slate.—The slate termed "unfading green" is greenish gray, a color it maintains indefinitely. It contains more pyrite and magnetite than the sea-green and splits less readily. Unfading-green slate is confined chiefly, though not entirely, to that part of the slate area which lies north of Poultney. It is used principally for roofing.

Purple and Variegated Slates.—The so-called "purple" slate is dark purplish brown, the purple color being attributed to a mixture of the red of hematite with the bluish green of chlorite. The "variegated" is greenish brown, with irregular purple patches giving a mottled effect, which is attributed to irregular distribution of hematite. Both types are interbedded with the sea-green and unfading-green slates but are less susceptible to color changes than are the sea-green varieties.

Mill-stock Slates.—Certain purple and green slates having poor cleavage are used for various milled products, such as floor tile, vats, mantles, baseboards, sills, steps, and to a small extent billiard-table tops, sanitary slabs, and blackboards. Some purple slates are well-adapted for electrical uses. Most of the slate used for milling purposes is obtained in the northern district, near Fair Haven, Vt.

Red Slates.—Red slates associated with bright green varieties of Ordovician age are found in Washington County, N. Y., near Granville. The red color is due to abundant hematite. These slates occur in beds

10 to 25 feet thick, and are used for granules and to a limited extent for roofing.

Flagging and Building Stone.—Slate for copings, flagging, terraces, ornamental walkways, and walls made entirely of slate or in combination with other stones is produced in increasing quantities, particularly in Washington County, N. Y. Very attractive sidewalks and porch floors are made by fitting together flagstones of various sizes, shapes, and colors.

Granules and Slate Flour.—Granules for the manufacture of prepared roofing are made of both red and green slate at Granville, Middle Granville, Poultney, and Hampton. Slate is also ground to a fine powder and sold as a filler for roofing mastic, paint, road asphalt, and various other products.

General Distribution of Quarries and Mills.—Aside from granules, flour, and slate for floors, walks, and walls the product of Washington County, N. Y., is roofing slate. Many slates are of the thick, heavy types known as architectural grades. Their rough texture and attractive, variegated colors adapt them for ornamental roofing material. A few large companies have quarries near Granville and Middle Granville, and many small quarry operators sell their products to them.

In the southern slate district of Vermont, which extends from Poultney to West Pawlet, the chief product is roofing slate. Numerous quarries are operated throughout this district and produce slates in a wide variety of color combinations. Granules are also manufactured, chiefly from green slates. In the northern district of Vermont, near Poultney, Fair Haven, and Hydeville both roofing and mill stock are produced. Several slate-finishing mills are operated, particularly in and near Fair Haven. Structural, electrical, and roofing slates are important products of this territory.

It may be observed from the above descriptions that Vermont and New York produce slates in an attractive variety of colors particularly well-adapted for roofing high-class residences and larger structures. The heavy architectural grades are sold widely for ornamental roofs. With proper color blending and graduation of size they produce effects unsurpassed in attractiveness by any other roofing material. More than 20 companies quarry slate in New York and more than 50 companies in Vermont.

Pennsylvania. *Lehigh District. General Features.*—The Lehigh district comprises Lehigh and Northampton Counties, Pa., and Sussex County, N. J. The Pennsylvania slates occur in a strip 2 to 4 miles wide on the south side of Blue Mountain, extending from Delaware Water Gap on the Delaware River southwest to a point 4 miles west of Lehigh Gap on the Lehigh River—about 32 miles. Quarries centered chiefly around Bangor, Pen Argyl, Windgap, and Slatington constitute the most

productive slate area in the United States. The Sussex County (N. J.) deposit, extending from Newton and Lafayette to the Delaware River, is regarded as an eastward continuation of the Pennsylvania beds.

Slate produced in Pennsylvania in 1929 was valued at $4,798,200, or about 42.7 per cent of the value of total production in the United States. Production in 1930 was valued at $3,634,258, in 1931 at $2,791,752, and in 1937 at $2,735,744. A small part of the Pennsylvania production was obtained from the Peach Bottom district, which is considered in a subsequent section of this chapter. Roofing and mill stock are both produced extensively, and there is a small production of granules and slate flour.

Geology.—A Cambrian and Ordovician dolomite and limestone plain 3 to 6 miles wide extends north and northeast from Easton, Pa., following the general direction of the Delaware River as far as Belvidere. The upper member, the Jacksonburg limestone, provides the well-known cement rock of the Lehigh Valley. The limestone dips northwest, and overlying it is the Martinsburg formation, which includes the slate beds. At the southeast the shales and slates are in contact with the underlying limestone and at the northwest dip under the Silurian conglomerate and sandstone of Blue Mountain. The slate belt is 1,600 to 6,000 feet wide, but only a few hundred feet are of commercial quality.

The slate formation consists of two lithologically different rock types. The lower section, known as the "hard-vein" belt is made up of hard closely bedded slates interbedded in places with sandstone. It occurs farthest south passing through Belfast and Chapman Quarries. Above it are beds of nearly pure sandstone, and higher still, a second type of slate, which is soft and thick-bedded, with occasional sandy layers. The upper section constitutes the "soft-vein" belt, which extends from East Bangor through Bangor, Pen Argyl, Windgap, Danielsville, and Slatington to Slatedale. From the structural relations it is evident that the soft-vein slate everywhere occurs nearest the mountain.

The slate beds consist of a succession of close folds generally overturned northward so that their axial planes have a general southerly dip. Folds are easily recognized by the curve of the ribbon. The slaty cleavage dips southward at various angles, usually ranging from 5 to 20°, and therefore intersects the ribbon at a high angle.

Varieties and Uses. Hard-vein Slate.—"Hard-vein" slate, as the name implies, is relatively hard compared with the overlying beds. It is used almost exclusively for roofing, walks, and masonry walls, as it is too hard for milling. The rock is blue-gray, with somewhat darker carbonaceous beds. The more siliceous beds have a faintly silvery sheen. Ribbons, consisting mostly of siliceous minerals highly resistant to weathering, are numerous and closely spaced. They scarcely deflect the cleavage, which is remarkably well-developed.

CHAPMAN QUARRIES DISTRICT.—The most productive district in the hard-vein belt is at Chapman Quarries station on the Lehigh & New England Railway. Quarrying began in this district about 1860. Numerous openings have been made, but only two or three of the largest have been quarried actively during recent years. The slate beds in this area are folded and contorted, synclines and anticlines appearing on quarry walls. The slaty cleavage, however, is remarkably constant, generally ranging from 10 to 20° in a southerly direction. The principal joints, which strike about N.60°E., are nearly vertical and form many of the smooth faces seen on quarry walls. The grain is vertical and strikes N.37°–53°W. While variations occur in different quarries the general structure is much the same throughout the district. For many years the larger quarries have continuously produced large quantities of roofing slate. Heavy, rough-textured architectural slates are produced in increasing quantities, and heavy flagging and grave vaults are made in limited amounts.

BELFAST-EDELMAN DISTRICT.—Typical hard-vein slate of this area lies within a radius of 2½ miles of Edelman on the Delaware, Lackawanna, & Western Railway. Only two quarries have been active recently, one at Edelman and one at Belfast. In the Edelman quarry major joints strike in a general northeasterly direction and are quite regular. Slaty cleavage dipping about 10°S. cuts across the intensely folded beds. A vertical grain trends about N.50°W. In the Belfast quarry the cleavage dips east at angles of 5 to 22°, while the grain trends about N.40°W. and is vertical. Roofing slate is the main product.

Soft-vein Slate.—The upper soft-vein member of the Martinsburg formation consists of thick beds of light to dark bluish gray slate alternating with thinner, almost black beds (ribbons). The wider ribbon-free bands are known as "big beds"; they are particularly prized, as they provide clear stock for blackboards and other of the higher-priced products. Ribbons, which consist of thin carbonaceous beds, have an important bearing on the value of slate, for most of them disintegrate upon exposure a little more rapidly than the main body. For this reason ribboned slate is not favored for the most enduring uses, though some of it will give good service for 50 or more years. Because of their carbon content ribbons are not good electrical insulators and therefore must be avoided in the manufacture of switchboards and panels. For certain exposed uses they detract from appearance, but as they do not affect strength greatly, ribbon slate is widely used for many structural applications, such as steps, risers, baseboard, wainscoting, etc. Its easy workability makes soft-vein slate particularly desirable mill stock.

"Hard rolls" is a name given to the sandy portions of beds which are usually discarded, partly because they dull tools rapidly and are therefore worked with difficulty and partly because the cleavage is inclined to be

curved or irregular. Siliceous knots, which are present in places, affect the workability of the slate and cause uneven cleavage.

In the eastern or Bangor-Pen Argyl part of this region, the soft-vein member of the Martinsburg formation may be separated into two parts—the lower or Bangor beds and the upper or Pen Argyl beds. The former extend from East Bangor through Bangor and thence southwestward, passing from ½ to 1½ miles south of Pen Argyl. The upper beds pass through the southern part of the town of Pen Argyl and through West Pen Argyl and Windgap. It is customary in the Pen Argyl and Bangor districts to recognize certain subdivisions called "runs," which include the several beds of slate exposed in a quarry or group of quarries. Generally accepted names are applied to the more important runs, and the slate in some instances is well-known to the trade by the name of the run from which it is obtained. In general, the slate of any particular run is fairly constant in quality from one quarry to another, although variations occur.

BANGOR DISTRICT.—The lower beds of soft-vein slate are slightly harder than the upper, and ribbons are somewhat closer together. Beginning at the top of the Bangor beds, the following runs generally are recognized: North Bangor No. 3, North Bangor No. 2, North Bangor, Bangor Union, Old Bangor, and Grand Central. Each is subdivided into certain characteristic beds on the basis of thickness, ribbon, and color. Seven or eight companies operate quarries near Bangor and East Bangor, where more than 30 quarries are or have been active. The main product is roofing slate which has won a high reputation through many years of satisfactory service. Some beds are suitable for mill stock, and several large mills are operated. Certain thin beds intermediate in color between the carbonaceous black of the ribbons and the light gray of the big beds are used for school slates.

PEN ARGYL AND WINDGAP DISTRICT.—The upper soft-vein slates that extend southwest from Pen Argyl are grouped into well-recognized runs in the same manner as those at Bangor. Beginning with the topmost beds the following runs appear in succession: Pennsylvania, United States, Diamond, Albion, Acme, and Phoenix. The runs are not in direct contact with each other but are separated by intervening beds 75 to 280 feet thick, consisting of unworkable slaty rock. Each run is made up of a series of individual beds; the Albion run, for example, consists of 12 beds with an aggregate thickness of 184 feet; some are big beds, some ribboned slate, and others unworkable rock. The Albion "gray bed" is of exceptionally high quality.

Eight or 10 companies operate quarries in and about Pen Argyl. The largest and deepest open-pit slate quarries in the country are in this territory; a maximum depth of 725 feet has been attained, and depths of 400 to 500 feet are not uncommon. Deep quarrying is not entirely a matter of choice; it is influenced by rock structures. Beds dip at very

steep angles and in places are almost vertical. As property lines or heavy overburden in many places restricts extension of quarries along the strike and as beds are of limited thickness, a great volume of production can be attained only by following the beds to greater and greater depths.

Rock structures are favorable for quarrying. Slaty cleavage generally dips south at a low angle, and quarry floors are maintained parallel

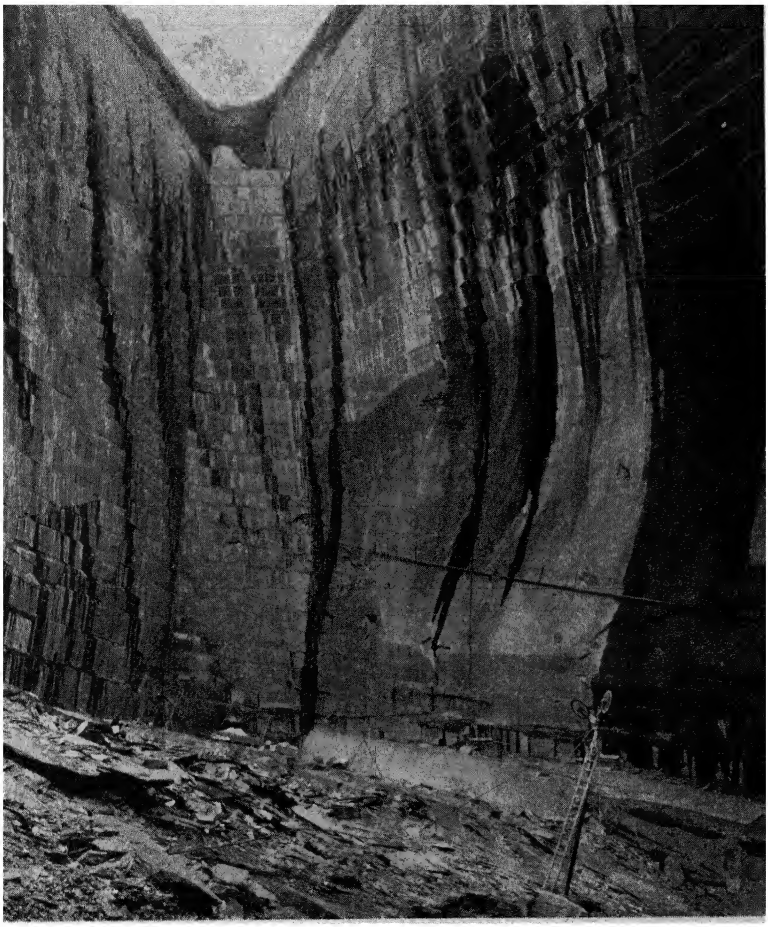

FIG. 42.—View from the bottom of a slate quarry 450 feet deep at Pen Argyl, Pa. (*Courtesy of Ingersoll-Rand Company.*)

to it. Open seams and loose ribbons provide smooth, uniform quarry walls in places.

Figure 42 illustrates a deep quarry in the Pen Argyl district. The curved wall at the right resulted from the presence of a loose ribbon.

In 1929 five companies were operating near Windgap about 2½ miles southwest of Pen Argyl. The same beds as at Pen Argyl are present; and

conditions are similar, although each quarry has its own peculiar structures.

Both roofing and mill stock are obtained from most of the quarries throughout the Pen Argyl-Windgap district, and large, well-equipped mills are associated with the quarries. Durable, unfading slates with straight, easy cleavage are used for high-grade roofing material; rough splitting slate and mill ends for heavy architectural roofing-slates; big beds for blackboards and large slabs of clear structural slate; smaller beds of high dielectric strength for panels and switchboards; and ribboned beds for various structural and sanitary applications. Granules and slate flour are manufactured to a limited extent.

SLATINGTON DISTRICT.—A westward extension of the soft-vein slate beds has been quarried extensively in western Northampton County near Berlinsville and across the Lehigh River in Lehigh County at Slatington, Emerald, and Slatedale. The quarries near Slatington occupy an area of about 3 square miles along Trout Creek and its tributaries. As in the eastern Northampton County district, quarrymen give special names to the commercial beds. Following the beds downward—that is, from north to south the following are recognized: Columbia, Manhattan, Locke, Star, Keystone, Mammoth, Big Franklin, Little Franklin, Washington, Trout Creek, Blue Mountain, Saegersville, and Peach Bottom.

The "Franklin big bed" and "Washington big bed," as they are sometimes termed, are the most widely known, as they provide clear stock of high quality in large sizes. Some of the beds mentioned may be duplications, for the folding is close, and the same bed could easily reappear several times. Complete anticlines or synclines are observable on some quarry walls, as the folding in this district is around axial planes that stand more nearly vertical than at Bangor and Pen Argyl and have the effect of repeating the outcrop of individual beds. The curvature is plainly marked by ribbons. Slaty cleavage is quite steep, in many places reaching 60 to 75°, though in some quarries it may be as low as 35°. Curved cleavage has been noted in some beds. The grain is nearly vertical and at right angles to the cleavage. Joints or "headers" dip at various angles. The rock is dark bluish gray, and most of it splits easily. About 10 companies were active in the district in 1930. A great many quarries have been worked, some of them to depths of 300 or more feet, but most of them are now abandoned. Slate is being mined locally, in addition to the usual quarry operations. Both roofing and mill stock are produced by all the companies.

New Jersey.—An eastward extension of the Pennsylvania slate beds crosses the Delaware River and extends into Sussex County, N. J., as far as Lafayette and Newton. The deposit is regarded as a continuation of the hard-vein slate occurring at Chapman Quarries and Belfast. Near Lafayette, where commercial development has taken place, the beds dip

about 18° northwest, while the slaty cleavage dips about 19° southeast. The grain is vertical and at right angles to the strike of the beds. The slate is blue-gray and intersected by numerous ribbons at 1- to 15-inch intervals. Like the hard-vein ribbons of Pennsylvania, they resist weathering.

For a number of years before 1918 roofing slate was produced from a quarry about 1½ miles north of Lafayette. The quarry was reopened in 1922 and again in 1928. Slate of high tensile strength, low porosity, and attractive color is obtainable in this district, but economical operation evidently has not yet been perfected, for activity ceased again in 1930.

Pennsylvania-Maryland. *Peach Bottom District.*—The slate belt of the Peach Bottom district is one-fifth to one-half mile wide, extending from about 1 mile northeast of the Susquehanna River in Fulton township, Lancaster County, Pa., southwest across the river, across Peach Bottom township, York County, and continuing about 3 miles in Cardiff township, Harford County, Md. Its total length is about 10 miles. Formerly about 1½ miles were beneath the Susquehanna River, but since the Conowingo Dam was completed a larger part of it is submerged. Quarries are situated near Delta, Pa., and Cardiff, Md.

The slate, bordered by schist, is regarded as of pre-Cambrian age and overlies older gneisses and serpentine. Three parallel belts 75 to 120 feet thick extend northeast-southwest, but their structural relations are obscure. Slaty cleavage is uniformly vertical or dips at a steep angle. One or more nearly horizontal joints pitching gently southward usually are present 40 to 60 feet below the surface and known locally as "big flat joints." They include 2 to 3 feet of crushed slate, the fracturing of which has evidently resulted from secondary crustal movement. Commercial slate occurs only below this joint. Other joints intersect the slate, some being vertical and others dipping at various angles. Inclined joints, with quartz veins and lenses, cause much waste. The grain dips 20 to 50° northeast.

As recorded on page 237, the first slate quarry opened in America was in the Peach Bottom district, and slate therefrom used on seven successive roofs over a period of nearly 200 years is still in excellent condition. Although Peach Bottom slate generally is recognized as of superior quality, the industry has never flourished. Lack of activity is due to unfavorable quarry conditions, which are discussed in a subsequent section on quarry methods in the various districts.

Peach Bottom slate is dark bluish gray, with a lustrous cleavage surface. It contains graphite, magnetite, and a little pyrite but is notably free of carbonate. An unusual feature is the presence of numerous small crystals of andalusite. The main product is roofing slate, which has an excellent reputation. At times a small amount of structural slate is made. Only two companies have produced during recent years,

Two large mills, one in Maryland and one in Pennsylvania, produce granules and slate flour.

Virginia. *Buckingham and Fluvanna Counties.*—Slate extends from Fluvanna County across the James River and southward over 5 miles. From fossils found in the beds the rock is identified as of Ordovician age. The slate occupies a zone about two fifths mile wide along Hunts Creek, a southern tributary of Slate River. At Penlan it strikes N.30°E., at Arvonia N.35°E., and on the north side of the James River 3½ miles north-northeast of Arvonia N.20°E. The best commercial slate occurs near Arvonia in a belt 200 to 250 feet wide and about 1 mile long. To the south of this area the slate is of good quality, but the belt becomes too narrow for profitable mining; to the north, while the belt becomes wider, the slate is poorer in quality and splits with greater difficulty.

Bedding dips southeast at steep angles of 80 to 85°. Slaty cleavage parallels bedding. Vertical dip joints strike about northwest; other joints run northeast and in diagonal directions. There are also gently undulating "flat joints" which the grain parallels. Closed seams or planes of weakness, known locally as "post," cross the deposit at 20- to 60-foot intervals and serve as headings for the benches. The post runs diagonally, causing much waste in places. A diabase dike 7 feet across was uncovered in opening a new quarry in 1930.

Nature has provided a very interesting index or guide to the best commercial slates. A certain easily recognized bed serves as a reliable marker in locating workable beds. This indicator bed is about 20 feet wide and consists of characteristically spotted or pitted rock. It occurs on the western side of the belt, and good slate always begins about 20 feet east of this bed.

Buckingham slate is very dark gray or slightly greenish, with a lustrous surface. It contains a little graphite, magnetite, and pyrite but is notably free of carbonate. It splits with difficulty, with a rough surface, which is an asset according to modern architectural demands for variegated texture. Virginia slate is so hard that channeling machines can not be used, and quarrying is done by drilling and blasting. As timed by the writer, a pneumatic drill bit 1 inch in diameter sinks at a rate of only 2 inches a minute. Except for small quantities used locally for monuments and a small but increasing amount for walks and terraces the entire production is roofing slate. It is very durable and has a splendid reputation. Slates from the roof of the McGuire residence in Alexandria, Va., which was built in 1820, show no discoloration or sign of deterioration. Three large companies were operating quarries in 1931. The largest excavations are 500 to 600 feet long, 250 feet wide, and 200 to 225 feet deep.

Albemarle County.—The slate outcrop of Albemarle County lies east of the Blue Ridge and 10 to 12 miles west of the Buckingham County

belt. Quarries have been opened at Esmont on Ballinger Creek, a small tributary of James River. The rock is intensely folded into a series of synclines and anticlines. Slaty cleavage dips northeast at an angle of 70° to 80°. Discontinuous vertical joints strike N.58°W. and are spaced 2 to 10 feet apart. Close, irregular jointing causes much waste in the upper levels. Both black and green slates occur, and the same beds appear repeatedly on account of close folding. One opening has been worked to a depth of about 200 feet. The slate is soft enough to permit channeling machines to be used in the quarry and circular saws in the mill. Both roofing slate and granules are produced.

During recent years roofing slate of good quality has been produced at Monticello, but no details of structure have been obtained.

States of Minor Importance.—The following States have been intermittent producers of slate on a small scale.

Arkansas.—The slate area of Arkansas extends about 100 miles west from Little Rock nearly to Mena and has an average width of 15 miles. The principal developments are near Norman and Slatington in Montgomery County. The rock is compressed closely in overturned pitching folds. In some places cleavage parallels bedding; in others it is oblique. Both red and green slates are obtainable, and near Mena, Polk County, greenish gray and black slates occur. Many attempts have been made to develop the Arkansas deposits, but none has been successful on account of the distance from markets, high freight rates, and large proportion of waste. Mill stock was produced years ago, but recent production has been confined to a small amount of flagging for walks.

California.—Between 1889 and 1915, when activity practically ceased, Eldorado County, Calif., produced considerable roofing slate, attaining a maximum of 10,000 squares a year in 1903 and 1906. Quarrying was conducted most actively near Kelsey. The slate which is of Jurassic age is bordered by a large area of diabase. The bedding is marked by numerous ribbons, which are generally within 10° of the plane of slaty cleavage, the latter being practically vertical with a N.25°W. strike. The ribbons are not of marketable quality. A series of joints parallels the grain, which strikes N.55°E. and dips 70 to 80 northwest. The rock is dark gray and resembles Pennsylvania slate in general appearance. A 6-mile aerial tramway was employed to carry the product to the railroad near Placerville. The Chili Bar quarry about 3 miles north of Placerville has been worked intermittently for the production of granules, and at times a similar product is produced in Tuolumne County.

Georgia.—The Rockmart formation of Polk County has been the most productive slate belt of Georgia, yielding bluish gray roofing slate, with some interruption, from 1880 to 1913, with a maximum output of 5,000 squares in 1894. The slate is of Ordovician age and is underlain with limestone. Bedding strikes N.20°–40°E. and dips southeast about

20 to 25°. Slaty cleavage strikes with the bedding and dips 40 to 45° southeast. Ribbons are spaced 2 to 5 feet apart in places, and joints are 15 to 18 feet apart. Decline of the industry is attributed to increasing cost and unsystematic development.

A second slate district of Georgia is in the Conasauga formation of Cambrian age. The best slate, which is greenish gray, occurs south of Fair Mount, Bartow County. The beds are greatly folded and contorted, with cleavage dipping 9 to 45°. A small amount of roofing slate was made prior to 1913, but recent production has been confined to green granules and slate flour.

Michigan.—A large deposit of black slate occurs at Arvon, Baraga County, close to water transportation. More than 50,000 squares of roofing slate were made before 1881, when the quarry was last worked. According to report the slate is of good quality, but the industry failed because of mismanagement.

Tennessee.—Purplish, greenish, and black slates, probably of Cambrian age, occur in Monroe County. Green slate has been quarried to some extent near Tellico Plains for granule manufacture, but operations were discontinued in 1928, and the plant was moved to Fair Mount, Ga.

Utah.—Green and purple slates occur in Slate Canyon about 2 miles southeast of Provo station. Purple slates are more abundant and have better cleavage than the green. Granules were produced in a small way prior to 1922.

GENERAL PLAN OF QUARRYING

The economical development of deposits involves many complex problems, because slate, having resulted from intense regional metamorphism, usually occurs in folded or steeply inclined strata. As pointed out in the discussion of the origin of slate, the rock consisted originally of clay deposited in horizontal beds on the sea floor. Materials forming each distinct original bed were deposited under fairly similar conditions and were uniform over wide areas. No matter how intense subsequent metamorphism may have been, changes were usually the same within the boundaries of each bed, and therefore slate as it appears today shows remarkably constant quality throughout the extent of each bed. Changes in thickness may occur as a result of folding, but from characteristic qualities certain well-defined beds may be recognized at points miles apart. Therefore, if high-quality slate is found in a certain bed an operator plans his quarry to follow this bed. Knowledge of geological structure is usually advantageous, as, for example, in regions where close folding brings a desirable bed to the surface in a succession of outcrops, where a pitching axis of a fold depresses a bed laterally below the limit of economic recovery, or where a fault carries a bed beyond the boundaries of a quarry.

The plan of a quarry is governed chiefly by geologic structures. In Northampton County, Pa., beds are marked clearly by ribbons and thus are easy to trace. Bedding dips at steep angles, ranging from 70° to vertical. Following desirable beds under such conditions carries quarries down 500 to 700 feet. Such quarries may be worked for years, with little expense for removal of overburden but with some attendant inconvenience in access and hoisting. As the slaty cleavage is nearly horizontal or dips at low angles quarry walls are very strong, with no apparent danger of bulging or collapse even at the greatest depths to which quarries are now worked.

In Maine the beds are narrow and vertical, and the cleavage is also vertical, a condition which makes walls weak and in constant danger of collapsing if open pits are sunk 200 feet or more. The necessity for deep mining, combined with the inherent weakness in the walls, led to the ingenious method of driving deep shafts with lateral tunnels and removing rock by overhead stoping. Slate in the Peach Bottom district of Pennsylvania and Maryland likewise has vertical cleavage, but through lack of foresight the weak walls were so overburdened with piles of waste that very expensive slides resulted.

In Buckingham County, Va., bedding and cleavage stand at angles approaching vertical, but cleavage is less perfect than in Pennsylvania or Maine, and the effects of freezing and thawing are less severe. The beds are thick enough to permit wide openings, and quarrying is not conducted at excessive depths.

In the New York-Vermont area bedding dips at an average angle of 40 or 45°, ranging in different quarries from 15 to 60°. This condition necessitates wide, comparatively shallow quarrying, for with vertical descent a pit may pass entirely through the desirable beds. Further development then demands extension along the strike. Extension of a pit down the dip of beds requires removal of an increasingly heavy overburden. Where beds are inclined moderately, underground methods have been followed in a few quarries in Vermont and near Slatington, Pa.

Steeply inclined open joints and "loose ribbons" are structures that demand careful attention, as they may endanger operations through slides of rock masses left without support. Several quarries have been closed because of such slides. A wise operator plans his quarry as a permanent industry and at the outset maps a plan that will permit untrammeled development indefinitely. Lack of capital has been the chief cause of inadequate development of many slate quarries.

QUARRY OPERATIONS

Stripping.—Stripping methods are described in some detail in a previous chapter. Where quarries are carried to great depths or where

underground operations are followed no stripping may be required for 10 to 20 years. It may become necessary at more frequent intervals in regions where quarries are comparatively wide and shallow. A heavy overburden of soil and decayed rock usually is handled by power shovels. Removal of overburden to an insufficient distance has often necessitated handling waste material a second time when workings are enlarged. More progressive quarrymen transport overburden and waste far enough to permit development for many years without rehandling.

Drilling.—Compressed-air, nonreciprocating, automatic rotation, hollow-steel hammer drills are the most popular. In a few quarries where no air compressor has been provided steam tripod drills are used. Churn drills are employed occasionally where there is a depth of 20 to 50 feet of waste rock that requires heavy blasting for removal. Soft-vein Pennsylvania slate may be drilled rapidly. A maximum of 240 feet of drill hole per man during an eight-hour shift has been noted. The hard-vein slate of Pennsylvania and the Virginia slate are drilled much more slowly.

To avoid damage to good slate, drilling in the adjacent country rock is sometimes necessary; and if such rock is highly siliceous, as in the Maine deposits, drilling may be much slower than in pure slate.

Blasting.—Commonly 10 to 40, or even 50, feet of slate nearest the surface is altered by ages of weathering and must be removed as waste before merchantable rock beneath can be reached. Dynamite blasts in tripod, hammer, or churn-drill holes are used to shatter the upper levels, but heavy blasting close to sound slate is carefully avoided. Waste immediately above good slate is commonly channeled, and then fractured for removal with light charges of black blasting powder.

Black blasting powder always is employed in commercial slate, as the higher grade explosives cause much waste. Very small charges may be utilized to advantage in making cross fractures or floor breaks, but in best practice drill holes for such shots are only three eighths to five eighths inch in diameter; and it is customary, even when firing with electricity, to place a length of fuse in a hole merely to take up space and distribute a small charge throughout the length of the hole. Shots may be fired with a fuse or by electricity.

Before channeling machines were introduced blasting was the chief method of separating the larger blocks, and the method persists in regions where the slate is regarded as too hard for profitable channeling or for sawing with wire. In such quarries walls are rough and irregular, blocks are rarely uniform or rectangular, and waste usually is excessive.

Wedging.—Wedges, used for making floor breaks in deposits where quarry floors parallel cleavage, may be driven in drill holes or in notches cut in the face. For subdividing larger masses the plug-and-feather method described in a previous chapter generally is used. Wedging is

much easier, and a smoother surface is obtained parallel to the grain than in other directions.

Channeling.—Channeling machines are described in the chapter on limestone. Steam-driven machines were introduced first in the slate industry about 1897 and were superseded by compressed-air machines. Channeling machines have been used widely in working the softer slates, notably in Pennsylvania and in Maine, but have not been favored in the New York-Vermont, the Peach Bottom, or the Virginia districts. Their employment in the softer slates marked a great improvement over previous methods, but wire saws have rendered them obsolete except in Maine quarries.

A machine known as a "bar channeler" or bar drill, previously described in the chapter on granite, preceded the modern channeling machine. It was introduced in slate quarries about 1887, but the process was so slow that it was not used widely; however, the method has persisted in some quarries where the "stunning" effect of channeling machines causes excessive waste.

Cutting with Wire Saws. *Early History.*—Wire saws have been used for many years in Europe for making long, deep cuts in slate, marble, limestone, and travertine quarries, but until recently have been used to a very limited extent in America. The only early record of successful use in the United States concerns one marble quarry in Colorado where about 1913 they were employed to cut out a mass of marble between two deep, open quarries. Their use as yard equipment for trimming blocks of limestone and marble is not uncommon, but wire saws did not become an essential part of any quarrying industry in American until general acceptance in the slate quarries of Pennsylvania during the summer of 1928.

Fig. 43.—Details of steel wire used as wire saw in quarrying, natural size. *a*, cross section.

Equipment and Method.—A wire saw is simply an adaptation by modern machinery of one of the most ancient stone-working methods. The man of the Stone age shaped his stone implements by abrasion or grinding; a wire saw utilizes this same principle, as it cuts stone from its original bed by a simple abrasive process. Sawing is done with a three-strand steel cable three sixteenths or one fourth inch in diameter and 800 to 2,400 feet long, running as an endless belt. Wire of the smaller size is illustrated in figure 43. Splicing requires skill and care, as the splice must be strong enough to withstand heavy tension and also be smooth and without enlargements. Any projection of the wire beyond the standard diameter would bind in a cut, and the wire would be broken. An 8- to 10-foot lap usually is provided in making a splice. Driving equipment ordinarily consists of a 10-horsepower electric motor with

worm-gear reduction running in oil. The driving pulley is one double-grooved cast-iron sheave, or a pair of single-grooved sheaves, 40 inches in diameter. The wire passes from one groove to the tension pulley, back to the second groove, and from there to the quarry where the slate is cut. It travels at about 15 feet a second.

The tension equipment is a suspended platform on which a weight of 800 to 2,000 pounds is placed to give necessary tension to the wire. The tension carriage may travel back and forth on a track; thus, the necessary adjustment in length of the wire can be made as the cut progresses. The arrangement of driving and tension equipment is shown in figure 44, *A*. Orienting pulleys mounted on standards conduct the wire from the driving equipment to the cutting unit in the quarry.

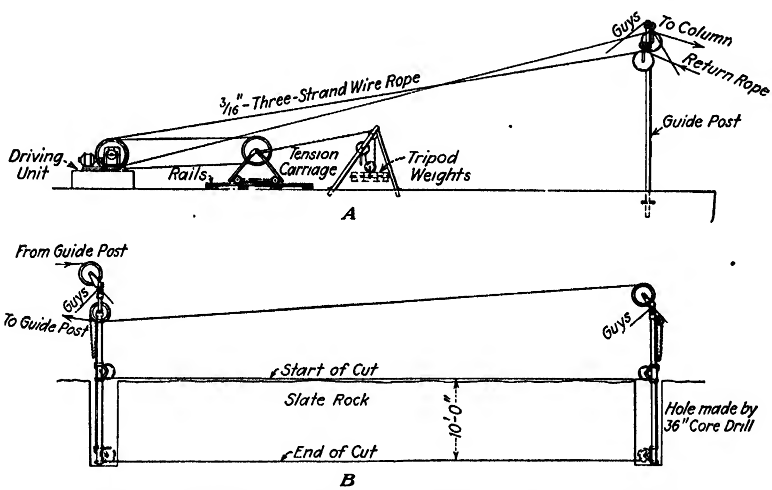

FIG. 44.—Diagram of wire saw. *A*, driving end; *B*, cutting end.

Equipment in the quarry includes a pair of angle-steel standards 14 to 18 feet long, each having one or two sheaves at the top for receiving and conducting the wire to a lower sheave which travels up or down by a rope-pull or chain-pull worm gear. An upper guide pulley is shown in figure 45. The standards, which usually are set 60 to 100 feet apart, are placed either on platforms over the edges of open benches or in holes 10 to 14 feet deep and large enough to accommodate the movable sheaves. By lowering the guide pulleys the wire is brought in contact with the slate and when fed with sand and water it makes a cut over the entire distance between the standards. The arrangement of the cutting equipment is shown in figure 44, *B*. The original equipment had guide pulleys 26 inches in diameter, but 18- or 20-inch sheaves are satisfactory. The heavy tension maintained on the wire prevents excessive upward curvature of the cutting strands, making it possible to complete a cut with the center not more than a few inches higher than the ends.

Holes or open benches must be provided to accommodate the standards carrying the movable guide pulleys, which descend as the cut progresses. Where there are open benches platforms are secured to the wall of the bench and the standards erected on the platforms. Where there are no open benches a core drill making a 36-inch circular hole is used for sinking holes in the rock. It consists essentially of a rotating notched-steel drum 30 to 42 inches high to which steel shot are supplied as abrasive. When the drum has cut to its full depth, it is elevated and moved laterally to permit removal of the core; then it is again put in place, and another section is cut. This process is repeated until a hole of the desired depth is obtained. Holes may be vertical or inclined at any angle up to 45°,

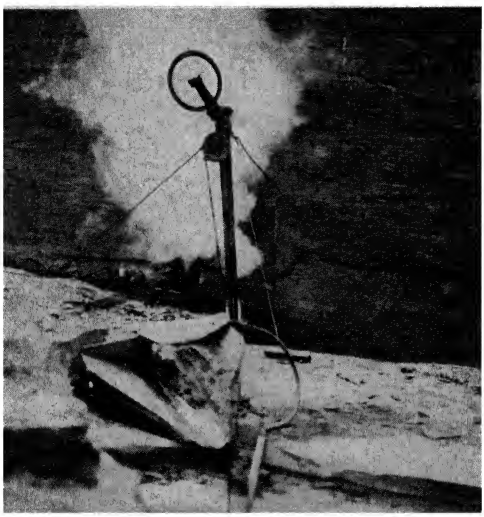

FIG. 45.—Wire-saw standard and guide pulley; sand box in foreground.

although cutting is slower in inclined holes. Inclination is commonly desirable to follow the direction of the ribbon so that the standards may be similarly inclined, making the cut parallel the ribbon and thus reducing waste. Sand and water are supplied through V-shaped boxes, as shown in figure 45. Sand is carried into the cut by a small stream of water from a rubber hose entering the upper end of the sand box. For a cut 80 to 100 feet long three or four sand boxes are used, one being placed as close as possible to the point at which the wire enters the rock.

A sand box developed in the Indiana limestone district, where wire saws are used for scabbling, consists of two compartments. One is kept nearly full of sand, and a stream of water supplied to it overflows through a hole into the second compartment, which contains water only. A thick sand slurry is drawn off continuously through a spigot and thinned to any desired consistency by the addition of a stream of water from the second compartment.

With a cut 80 feet long in the soft-vein slate of Pennsylvania the cutting rate is approximately 4 inches an hour. At this rate the guide pulleys should be fed downward about 1 inch every 15 minutes. A convenient measure of cutting accomplishment is the surface area obtained by multiplying the length of a cut by its depth. Thus, a cut 80 feet long and 10 feet deep provides 800 square feet of surface. Figure 46 shows the lower sheave and the wire where it emerges from the cut.

Introduction of Wire Sawing in Pennsylvania.—The United States Bureau of Mines, the National Slate Association, and a group of Pennsylvania slate producers cooperated late in 1926 in the purchase of wire-saw equipment from a Belgian firm. The first cuts were completed early in 1927, and the unqualified success attained led to its almost immediate and general acceptance by the slate industry of Northampton County, Pa. Within two years about 30 wire saws and 12 core drills were operating, and work with channeling machines was practically abandoned. Many improvements in equipment were worked out, and several American firms undertook its manufacture. Its successful use in slate has led to its introduction in some limestone and sandstone districts.

FIG. 46.—Wire saw at the point where it leaves the cut.

Cost of Cutting.—Few details of the cost of operating with wire saws have been obtained. The records of one company provide fairly complete figures for 11 months' operation of wire saws and core drill, although

the labor had to be estimated in part, as it was diverted to other work at times. During the period covered, 44 wire-saw cuts totaling 22,753 square feet of surface were made. As nearly as can be determined the total cost, including labor, power, repairs, supplies, and interest on the investment, was 14.3 cents a square foot. In making these 44 cuts, 35 core-drill holes were required. To obtain a figure comparable with channeling-machine costs, the core-drilling cost for each square foot of surface sawed, amounting to 10.1 cents, must be added, making a total cutting cost of 24.4 cents a square foot. This record dated from the beginning of operation of both the wire saw and the core drill. The efficiency of new equipment of this character is very poor during the first few months of operation; therefore, the cost figures given probably are much higher than those obtainable toward the end of the 11-month period.

Channeling-machine costs in the same quarry have been calculated in two ways: (1) The average daily footage over a 5-month period was divided into the total cost of channeling-machine operation, estimated at $20 a day, giving a figure of 64.5 cents a square foot; (2) the actual channeling-machine cutting in square feet was taken for a 19-day period, and the total labor, supplies, repairs, power, and interest on the investment for that period were charged to it. This method gave a cost of 73.1 cents a square foot. For the same footage, therefore, channeling-machine costs in this particular quarry are two and one-half to three times as high as wire-saw costs, even when the latter probably are materially higher than the average costs under normal operating conditions with skilled workers. A rate obtained by another quarry company was 18.9 cents a square foot for wire saws compared with 50 to 70 cents for channeling. Several years' experience by many operators has confirmed the early favorable estimates and has firmly established the conviction that the wire saw is the most economical means of cutting slate.

Advantages of Cutting with Wire.—Aside from the definite saving in cost of operation, as previously mentioned, the wire saw has other advantages, the most important being reduction in waste of rock. Search for a practical means of reducing excessive waste was, in fact, the incentive for the original experiments, and results have fully justified the effort. In making a cut a wire saw removes about one ninth as much material as a channeling machine, because a cut made with wire is only about 1/4 inch wide, whereas the width of a channel cut is 2 1/4 to 2 1/2 inches. Still more important is the fact that a channeling machine wastes much rock on either side of a cut through shattering or "stunning," but the wire, cutting by simple abrasion, leaves the rock unimpaired. Formerly many subdivisions into blocks were made by wedging along the grain or sculp, and much stone was wasted because of irregularities in fractures. Separation of blocks with wire results in smoother, straighter surfaces

with less waste. In some quarries the grain and ribbon meet at oblique angles, commonly approaching 60°. By channeling parallel with the ribbon and wedging on the grain angular blocks are obtained, and in cutting them to cubical mill stock many triangular masses of good slate are wasted. It is customary now to make wire-saw cuts parallel to and at right angles to ribbons, thus producing right-angled blocks that are utilized for mill-stock products, with a saving in stone of 10 to 15 per cent over former methods.

It is difficult to determine accurately the saving of rock accomplished by using a wire saw. No records of the gross tonnage of rock quarried have been kept under either former or present conditions. Various operators estimate a saving of 30 to 50 per cent. Other advantages are speed of operation, adaptability for continuous work during day and night until a cut is completed, simplicity and ease of operation, and ability to make inclined cuts conform with ribbons or other rock structures. Through this new method of making primary cuts, with consequent reduction in cost of operation and better utilization of raw materials, an annual saving to the Pennsylvania slate industry of at least a quarter of a million dollars has been accomplished. Quarry methods have been revolutionized, and the industry has been established on a more secure basis. Other slate regions have been slow in following this lead, but experiments are contemplated, and after fair trial and patient effort to overcome the difficulties peculiar to each deposit, definite success will no doubt be attained.

Floor Breaks.—Methods of separating masses of slate at the quarry floor vary greatly, depending upon the structure of the rock. In Pennsylvania and in the New York-Vermont district, where slaty cleavage dips 5 to 45°, a quarry floor is maintained parallel with cleavage, and floor breaks are easily made by splitting in that direction. Notches are cut in the face and wedges driven into them, a process known as "driving up splits." For separating exceptionally large masses drill holes are projected at the floor of the bench to parallel the slaty cleavage, and a fracture is made by means of small charges of black blasting powder. Where slaty cleavage is vertical or nearly so floor breaks are made with greater difficulty. Wherever possible horizontal seams are utilized.

Subdivision of Blocks.—In quarries where the floor parallels slaty cleavage most primary blocks are too large to be hoisted to the surface. Subdivision parallel to cleavage is accomplished by cutting notches in the face of the bench in a line parallel to the cleavage and about 18 inches or 2 feet from the top of the bench. A split is made by driving wedges in the notches. Longitudinal vertical fractures are made by drilling and wedging in the direction of the grain. Breaks across the grain are made in the same manner, but drill holes must be closer together than where they are parallel with the grain.

Block Raising.—After a block of the desired size is broken loose, several men working simultaneously raise it by heavy bars with curved

ends, used as levers. Freeing the rock is sometimes slow and difficult, not only because of its weight but because of many interlocking corners that must be actually broken. The most effective work results when the energies of all the men are applied to their bars at exactly the same moment. To obtain such unanimity a foreman frequently leads in a sing-song rhyme, the men joining and keeping perfect time with their crowbars. When a block is raised sufficiently a fragment of stone or a wedge is dropped in the crack, the bars are placed in more advantageous positions, and the process is continued until a hoist chain can be passed under the block.

Hoisting.—Wooden derricks and compressed-air hoisting engines are used in the Monson (Me.) district, but in practically all other districts overhead cableway hoists are employed. Derricks may be advantageous where a quarry is small or where, as in Maine, rock is removed from deep, narrow quarries or from mine shafts. In most regions, however, pits are so wide that a derrick boom can not reach all parts. For large pits three to six parallel cableways are commonly required to serve properly all parts of an excavation. The main cables range in diameter from 1½ to 2¼ inches, and the draw cables from ½ to ¾ inch. Most of them are designed to carry 3 to 5 tons. Cable spans between supports (wooden or structural steel masts) range from 500 to 1,800 feet. An advantage of the cableway system at many quarries is its ability to convey waste rock to the spoil bank by a single handling. Carriages equipped with automatic dumping devices are widely used. Supplementary derricks are used at some quarries for hoisting from pits or for yard service.

Signaling is usually done from a small house known as a "motion shanty," which overhangs the brink of a pit in such a position that a signal man has a clear view of the entire quarry floor. (See fig. 42.) By means of an electric button for each cableway the signal man sends to hoist engineers the messages which control all hoisting in the quarry. At some quarries, particularly in the Vermont-New York district, a board arm is used in place of electric devices. A board about 2½ feet long and 5 or 6 inches wide, pivoted near one end, is attached to the roof of the motion shanty and moved by a wire leading inside. The signal code is based on the motions of the board.

The only means workmen have of entering or leaving the deeper quarries is by cableway pan. A special signal is given when men rather than materials are being conveyed, so that hoist engineers may exercise special care. Hoisting accidents rarely occur.

QUARRY METHODS

Influence of Rock Structures.—The various processes by which blocks of slate are separated from their original beds and hoisted to the surface are covered in preceding paragraphs. There are many variations in the manner in which these processes are combined, and differences in

method depend chiefly on rock structures. Ease of splitting, direction of slaty cleavage, direction of grain, position of joints, and dip of beds influence the method. Slate can not be quarried successfully without detailed knowledge of these physical properties, and familiarity with them is gained only by actually working with the rock for some time. A quarryman learns to know his rock, and this knowledge guides him in his choice of methods. Quarry methods in their relation to rock structures in each of the principal producing districts are covered in following pages.

Pen Argyl-Bangor District.—The slate area of eastern Northampton County includes quarries in and about Windgap, Pen Argyl, Bangor, North Bangor, and East Bangor. The output of this region exceeds that of any other slate district in the United States.

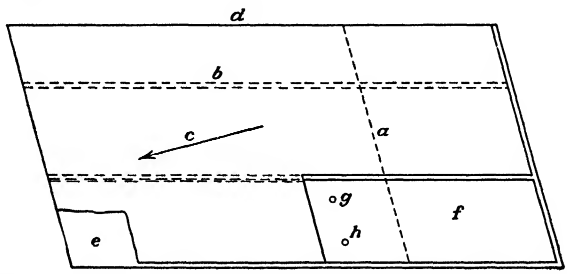

FIG. 47.—Rock structures and quarry plan at a typical Pen Argyl, Pa., slate quarry. *a*, direction of grain; *b*, ribbon; *c*, direction of dip of slaty cleavage; *d*, "loose ribbon;" *e*, drainage sump; *f*, mass of slate ready for floor break; *g*, *h*, drill holes for "scallop" or "sculp" blasting.

The strike of the rock is in general east-west but differs considerably in different quarries. The structural feature that has greatest effect on the quarry plan is the steep dip of beds, as indicated by ribbons. In several deep quarries the ribbon is vertical or curves back and forth from north to south in gentle, sweeping folds, usually at steep angles, though in some quarries at East Bangor it dips only 30 to 40°. In general, however, beds are so nearly vertical that the region is characterized by deep quarries with vertical or nearly vertical walls. Loose ribbons and open joints may commonly be utilized to take the place of channel or wire-saw cuts. Joints are generally spaced to permit removal of large blocks.

A second structural feature which is decidedly favorable is a slaty cleavage dipping at low angles, ranging from 5 to 30°. Quarry floors are maintained parallel to cleavage; thus, blocks are easily separated, and most of the floors are flat enough to be worked conveniently.

The positions of ribbon and grain govern the direction of cuts in a quarry. In some quarries they intersect at nearly right angles; in others, at angles of 70 or 80°. Before wire saws were introduced it was customary to channel parallel to the ribbon and to make cross breaks parallel the grain, either by wedging in drill holes or by using light charges of black

blasting powder. This resulted in the production of angular blocks, as indicated in figure 47, and in cutting such blocks into right-angled mill stock the waste was excessive. Since wire saws have been used it is customary to make cuts parallel to and at right angles to ribbons, producing rectangular blocks that may be cut advantageously into structural products. However, for roofing manufacture angular blocks commonly are used because there is less waste in reducing them to thin roofing than in cutting them into slabs or cubical stock.

In opening up a new floor with wire saws core-drill holes are sunk in the corners of the quarry, and from them wall cuts may be made in two directions at right angles. Core drilling is slow and expensive, therefore operators usually plan to utilize the holes to best advantage. Where a series of parallel cuts is to be made four holes may be drilled, as shown diagrammatically in figure 48. Wire-saw cuts are made as indicated at *b*, and the slate lying between them is removed. A trench is thus formed in which a standard may be placed in any desired position for making the subsequent cuts, *c*.

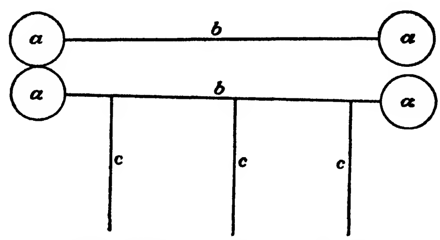

FIG. 48.—Method of cutting a channel in which standards are placed for transverse cuts. *a*, core drill holes; *b*, wire saw cuts to make channel; *c*, subsequent transverse wire saw cuts.

A wire-saw cut is only one fourth inch wide, and blocks may jam in removal if proper precautions are not taken when a new bench is opened. To facilitate removal of key blocks cuts are not made parallel but converge, as shown in figure 48. Binding is avoided by removing blocks first at the wider end of the wedge-shaped mass. The cuts also are inclined slightly toward each other, so that the mass of rock between is narrower at the bottom than at the top; then, as wedges are driven and blocks lifted the wider space in the upper levels provides ample room for any necessary lateral movement.

The advantages to be gained from wire saws are now generally recognized, and they are widely used to make numerous parallel cuts whereby slate is obtained in smooth, rectangular blocks. Operators are beginning to realize the advantage of numerous cuts; consequently, the general appearance of quarries is markedly changed. Instead of curved, irregularly broken bench walls, floors rise from bench to bench in regular steps resembling those of a marble quarry. Wire-saw equipment in process of making a cut 80 feet long is shown in the center of figure 49. The walls at the upper left corner were cut with wires.

Slatington District.—The Slatington district, comprising the quarries of Lehigh and eastern Northampton Counties, Pa., is characterized by a series of close folds with east and west axes that pitch east. The ribbon

is distinct, and many loose ribbons or open bedding planes greatly facilitate quarrying. Because of the close, repeated folding quarrying is complex, and an operator must have a clear idea of the rock folds in and about his quarry to develop the slate to best advantage. A succession of folds may cause a bed of high-grade slate to reach or approach the surface in several places. Probably in some quarries what has been regarded as a succession of good beds is merely a single bed brought to the surface by repeated folding. Some quarries are on synclines and others on anticlines; still others are worked on single limbs of large folds.

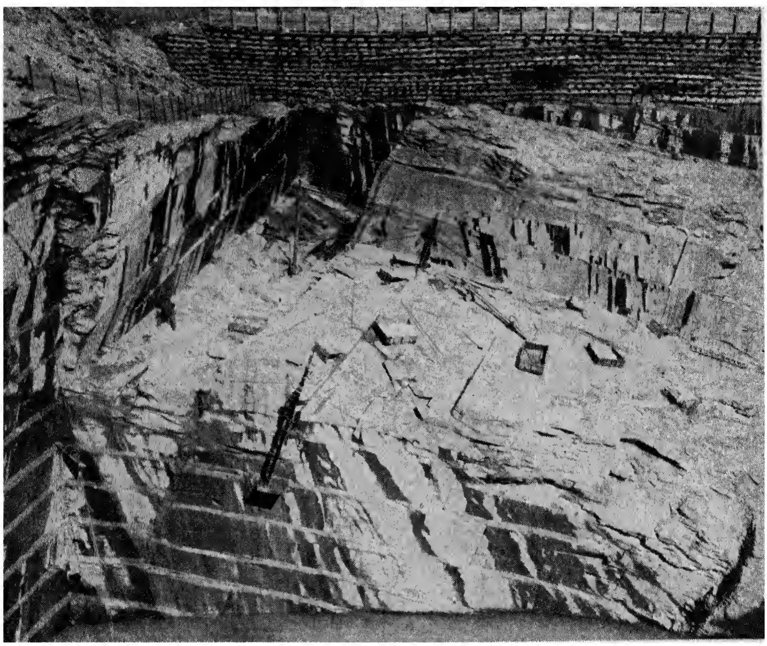

Fig. 49.—A Pennsylvania slate quarry, illustrating method of developing a new bench with wire saws; standard holding guide pulleys in foreground. (*Courtesy of Ingersoll-Rand Company.*)

A remarkable feature of the Slatington district is the uniform dip of slaty cleavage. With few exceptions, it dips 60 to 75° south, irrespective of the folding of the beds. The sculp or grain is also remarkably constant, crossing the rock generally a little east of south, and dipping to the east at a steep angle, approximately 85 to 88° from the horizontal. Hence, following the sculp tends slightly to undercut the east walls of quarries.

Joints and loose ribbons are utilized for headings and bench floors. If no open seam or ribbon is available floor breaks must be made in the hard-way direction, which gives rough, uneven floors. The downward curvature of a high-grade big bed under a great thickness of waste rock

has led to the development of underground methods. One quarry near Berlinsville has quite extensive underground workings.

Hard-vein District.—Structures of the hard-vein slate at Chapman Quarries and Belfast, Pa., are similar to those in the soft vein of eastern Northampton County. Slaty cleavage dips 5 to 15°, and quarry floors are maintained parallel with it. Wire saws are used successfully, although the rate of sawing is somewhat slower than in the softer slates. A vertical grain is utilized in making cross fractures.

Granville-Fair Haven District.—In Washington County, N. Y., and Rutland County, Vt., the slates dip at angles approaching 45°. Quarries are relatively shallow because the depth of overburden becomes very

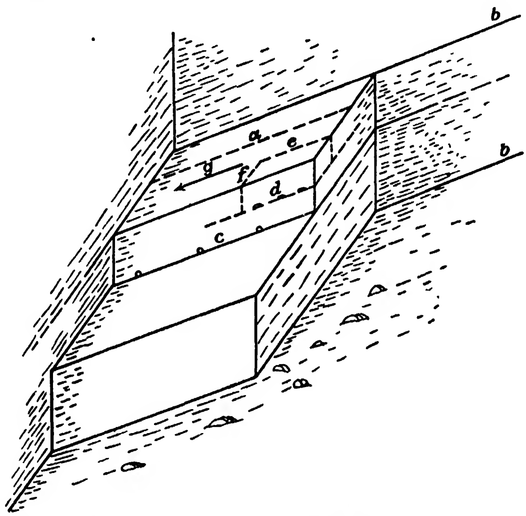

Fig. 50.—Rock structures and method of separating blocks in a quarry near Fair Haven, Vt. *a*, grain direction; *b*, open bedding planes; *c*, split holes; *d*, notches for wedging; *e*, break on grain; *f*, break across grain; *g*, dip of beds and slaty cleavage.

heavy in following down the dip. In some workings near West Pawlet, however, the beds dip steeply, and quarries are deep. Slaty cleavage is at steeper angles than in Northampton County, Pa., ranging from 10 to 30°. Quarry floors parallel the cleavage and are inconveniently steep in some quarries. Channeling machines are not used in this territory, as it is claimed that the rock is too hard for successful operation. Vertical joints are utilized wherever possible for walls and bench headings. If joints are not available fractures are made with charges of black blasting powder. Rock structures and methods in a typical quarry of this district are shown in figure 50.

Open beds, as indicated at *b*, commonly occur at intervals of 5 to 7 feet and are thus spaced conveniently for bench floors. Cleavage parallels bedding. If a floor is tight, holes are drilled along the bed from the open side, as shown at *c*, and very light charges of black blasting powder

are fired in them to jar the rock and free the bed. When the floor is free, a break is made on the grain by blasting in holes drilled the full depth of the bed. One hole is made for about each 15 feet of the desired break. "Foot joints" or "headers" are commonly utilized to form the third free face, but if they are not available, blasting is used. Large masses are thus set free, and further subdivision is made first by driving wedges in notches cut in the face, as shown at *d*, and then by using plugs and feathers in drill holes parallel to and across the grain, as shown at *e* and *f*.

In some quarries in the southern part of the slate area the dip of beds and cleavage approaches 60 or 70°; consequently, underground methods have been followed. Webs or elongated pillars of slate are left at intervals to support the steep, overhanging roof.

Overhead cableway hoists are used almost universally. Roofing slate is manufactured at the quarries, although mills for structural and electrical slate usually are situated at near-by towns.

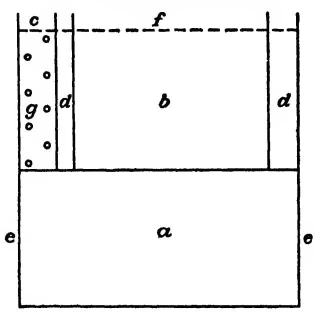

FIG. 51.—Vertical section of drift for overhead stoping, Monson, Me. *a*, drift; *b*, 10-foot slate bed; *c*, 2-foot slate bed; *d*, quartzite beds; *e*, open vertical seams; *f*, horizontal roof seam; *g*, drill holes for blasting.

Peach Bottom District.—Although Peach Bottom slate has a nation-wide reputation for high quality, in some respects quarry conditions are unfavorable. In a number of quarries steeply inclined open joints have permitted unsupported masses of rock to slide into the pits. The tendency toward wall collapse is increased through the presence of a vertical cleavage which weakens walls and makes them incapable of supporting heavy loads. Channeling machines are not used, partly because the vertical cleavage is unfavorable and partly because the rock is considered too hard. Benches are worked to open joints wherever possible. If no flat joints occur floor breaks must be made by blasting across the cleavage.

Monson District.—Conditions at Monson, Me., are similar to those in the Peach Bottom area, except that the best beds are relatively thin. Both bedding and slaty cleavage are vertical, and much of the highest-grade slate is obtained from one 10-foot bed. Deep quarrying in narrow opencuts was beset with many difficulties, owing to bulging or collapse of the walls. Cross supports, consisting of steel I-beams and concrete, were constructed at great expense in an effort to hold the walls apart, but at depths beyond 300 feet they were inadequate. An overhead-stoping system was then introduced and has been very successful. The first step was to project drifts right and left at the old quarry floors about 300 feet below the surface. They were driven 80 to 100 feet along the slate bed, and vertical wall seams and horizontal floor and roof seams were of great assistance. The procedure when a drift is completed is shown

in figure 51. At the northwest side of the drift, or at the left, as shown in the figure, a 2-foot slate bed, *c*, is separated by a few inches of quartzite, *d*, from the 10-foot slate bed, *b*. Good slate could be obtained from the 2-foot bed, but as the slate drills much more easily and rapidly than the quartzite, holes are drilled in the narrow bed, which is largely destroyed in quarrying. Drills are mounted on scaffolds and holes laid out on 16-inch centers and staggered, as shown at *g* in the figure. The depth of holes is governed by the position of the back seam, but it averages about 12 feet. The holes are loaded with light charges of black blasting powder and fired singly, beginning at the lowest. They are staggered to prevent the discharge of explosive in one hole from shattering the rock surrounding the succeeding hole. The narrow band of quartzite serves as a cushion and prevents shattering of good slate in the 10-foot bed. A mass of stone is worked down in this way until an upper seam is reached, as shown at *f* in the figure; then a final shot is discharged in a vertical hole drilled in the back corner at the southeast side to clear down all the slate to the open seam. From the mass of stone thus thrown down all good material is selected, hauled to the drift entrance by cable, and lifted to the surface by derrick hoists. Waste slate is left on the floor, and the heavy cost of removal is thereby saved. Thus, the floor is constantly built up with waste; for ideal operation it should keep pace with the upward progress of stoping from the roof. Waste is not sufficient in volume to build up the floor as fast as the roof is elevated, and additional rock is blasted from drift walls to keep it within easy reach of the roof. The drift is gradually worked upward toward the surface.

The method proved so successful that one company put down a shaft 1,000 feet deep and drove lateral tunnels from its bottom. Thus, a reserve of slate is provided for many years' constant mining. Advantages of the stoping method are: (1) The great saving occasioned by leaving waste rock in the pit; (2) reduction in hazard from roof falls, as the floor is at all times only a short distance below the roof; (3) reduction in hazard from fragments of falling rock during hoisting or from falls of rock from walls or upper edge of excavation; (4) elimination of impediment to operation from snow, ice, or inclement weather; (5) absence of danger from collapsing walls.

Where a series of many parallel slate beds is worked open-pit methods are followed. Channeling machines are used, but they cut rather slowly on "edge-grain" rock.

Arvonia District.—Slate structures of Buckingham County, Va., are similar to those in the Peach Bottom and Monson districts, in that bedding and slaty cleavage are nearly vertical, ranging from 80 to 85°. Open-pit methods are employed, and some quarries reach a depth of 225 feet. Walls are quite secure, with no apparent danger of collapse. Buckingham slate is so hard that no successful means of cutting it has yet been found.

In opening a new floor a trench 6 to 10 feet wide and 12 feet deep is first made, usually in a zone of defective rock, as the heavy blasting required would destroy good slate. Benches are always terminated at closed seams or "post," along which the rock breaks easily. From the bottom of the trench horizontal holes are drilled about 12 feet deep, and about 12 feet back from the edge of the trench steeply inclined holes are sunk parallel to the slaty cleavage. Vertical holes are drilled also along the "post." Black blasting-powder charges are fired simultaneously in all the holes, and thus a mass of slate is broken loose. A disadvantage of the method is fracturing in three planes simultaneously, which shatters the slate excessively. According to best quarry practice a fracture should be made by blasting only when there are five free faces instead of three.

YARD TRANSPORTATION

Slate blocks transported to quarry banks by cableways usually are placed on small cars and conveyed to splitting sheds or mills for treatment. For this haulage, gasoline locomotives are popular. Sometimes finishing mills are located in towns several miles distant from quarries, necessitating transportation by motor trucks or other means.

An important part of yard transportation is involved in the disposal of waste rock. Tracks from quarry banks usually lead by a moderate to steep incline over a waste heap, which gradually increases in height and in lateral extent as cars loaded with waste are hauled by cable and dumped at the end of the track. In some instances quarry waste is conveyed directly by overhead cableways, and if an automatic trip is provided no labor is required for disposal.

Transportation also involves conveyance of finished products to railway sidings or storage yards. As roofing slates often are split at shanties on high waste heaps the slates are conveyed down to the normal ground level by cable cars. For this purpose long eight-wheel cars commonly are used. In many places where transportation lines are not immediately available teams and wagons or motor trucks are used for both short and long hauls.

A unique method of transporting slate from quarry to railway is an electrically driven aerial tramway 2 miles long at South Poultney, Vt. It carries 400 buckets and has a capacity of about 200 squares a day. Two men load and three unload the buckets.

MANUFACTURE OF ROOFING SLATE

The manufacture of roofing slate is the oldest branch of the industry, and, strangely enough, the essential processes of splitting and trimming are conducted in the same way as when the industry was in its infancy. Many years ago a slate-splitting machine was invented and used success-

fully in an experimental way, but never for commercial production. This machine split the slate by rapid impact of a flexible steel blade.

Shanty Method.—What is known as the "shanty method" of making slate dates back to the beginning of the industry and is still widely used. Quarry blocks of suitable slate are conveyed directly to splitting shanties, which usually are high on waste heaps. The shanties are only large enough to accommodate two men—a splitter and a trimmer—and are heated in winter by small coal stoves.

The first process is known as "block making," a reduction of large masses to sizes suitable for splitting. Blocks are split to any desired thickness by driving wedges in the direction of slaty cleavage. They are then "scalloped" longitudinally in the grain direction by wedging in plug holes.

Intimate knowledge of the physical properties of slate is essential in breaking and splitting blocks properly. A skilled slate worker drives a wedge or plug until a strain is placed on the rock; he then procures a straight break by striking a blow with a wooden sledge at a particular point on the rock; he can thus within certain limits force a fracture where desired. The slate is split on the grain into masses about 14 to 24 inches wide, and these are then broken across.

Various methods are used to subdivide slate masses across the grain. The corners may be notched with a chisel or with a small saw and a smooth, even break obtained by striking one or two heavy blows with a large wooden mallet. To cushion the blow and thus preserve the slate from damage a thin flake of slate or a handful of fine slate rubbish usually is placed on the surface of the rock where the mallet strikes. Slates that break with difficulty may be sawed across with circular saws.

After they are broken across the cleavage the masses of slate are split parallel to the cleavage with a hammer and special chisel known as a "splitter"; the thicknesses thus produced are sufficient for eight slates each. The thickness of a slab is always measured with the splitter. Thus, if a thickness of $\frac{3}{16}$ inch is required for the finished slate, the splitter blade is eight times $\frac{3}{16}$ inch, or $1\frac{1}{2}$ inches wide; if the thickness is to be increased slightly the blacksmith is instructed to make the splitters a little wider.

Blocks are not allowed to dry out until finally made into roofing slates, as they split with much greater ease if the quarry sap is not allowed to evaporate. Maine slates are said to be an exception to this rule, as they split readily when dry. Blocks are made in the yard and finished blocks piled in the shanty. Here a slate splitter sits on a low seat with a block of slate resting against his knee. His tools are a wide, flexible, splitting chisel and wooden mallet. Blocks always are split in the center until slates of finished thickness are obtained. Some slates are split from the ends of the blocks and others from the sides. For tough-

splitting slate the chisel may be greased. A pneumatic chisel that has been used successfully in Vermont is impelled by rapid vibrations on the same principle as a pneumatic drill or stone-dressing tool.

A trimmer takes the slabs from a splitter and cuts them rectangular. The trimming equipment most often used, particularly in Pennsylvania, is a straight blade about 3 feet long, run by a foot treadle. The outer end of the blade is attached to an overhead spring pole, so that the blade strikes repeated blows when once set in motion by the treadle. Another common type is a rotary trimmer which has a curved blade similar to the cutting blade of a lawn mower. Most trimmers of this type are run by foot treadles, though at some plants they are belt-driven from a countershaft.

The steel gage bar on which slates rest for trimming has a series of notches which serve as guides in trimming to standard sizes. A skilled trimmer can determine very quickly the size to which each slate will trim to best advantage. The following table shows the standard sizes, in inches, of roofing slates carried in stock by most companies:

SLATE SIZES FOR SLOPING ROOFS

10 × 6	14 × 9	18 × 12
10 × 7	14 × 10	20 × 10
10 × 8	14 × 12	20 × 11
12 × 6	16 × 8	20 × 12
12 × 7	16 × 9	20 × 14
12 × 8	16 × 10	22 × 11
12 × 9	16 × 12	22 × 12
12 × 10	18 × 9	22 × 14
14 × 7	18 × 10	24 × 12
14 × 8	18 × 11	24 × 14

SLATE SIZES FOR FLAT ROOFS*

6 × 6	10 × 6	12 × 6
6 × 8	10 × 7	12 × 7
6 × 9	10 × 8	12 × 8

* Flat-roof slates for ordinary service usually are 3/16 inch thick. For promenades or other extraordinary service they may be 1/4 to 3/8 inch thick.

To facilitate handling roofing slates racks with a series of shelves divided into compartments are provided within easy reach of the trimmer. Slates are sorted according to size and quality as they are made, and a section is reserved for each class. Once a day, either just before closing time or early in the morning, the slates are loaded on cars and taken to the piling yards. A typical roofing-slate piling yard is shown in figure 52.

Mill Method.—One efficiently planned roofing-slate mill has been operating for many years near Poultney, Vt. About 1925 several companies in Pennsylvania erected and equipped mills for the same purpose. A plan of a typical mill is shown in figure 53. Blocks are brought into the mill on cars and stored at *c*. The mills are equipped with overhead traveling cranes or derrick hoists. Slate blocks are cut to desired

lengths with circular saws. By using saws objectionable "ribbons" or "hard ends" may be cut off, and thus many blocks which would be thrown away by the old method may be used. A saw cut provides a smooth surface, which makes splitting easier and also tends to conserve slate, for it is straight, while the breaking method often results in crooked and uneven fractures. One company has equipped its mill with a 60-inch diamond saw for cross cutting blocks of "hard-vein" slate. It is claimed that waste is reduced at least 15 per cent thereby, and mill production per man is increased a like amount. In mills one blockmaker and helper can provide blocks for two splitters. By the shanty method a splitter spends part of his time making blocks, piling slates, or shoveling rubbish; by the mill method he splits practically all the time. All

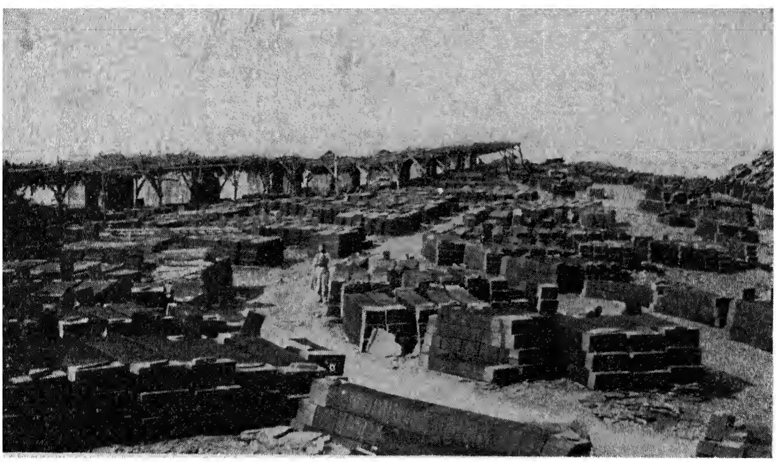

FIG. 52.—Typical roofing-slate piling yard with splitting shanties in background.

trimming machines in mills are power-driven; thus, the tiring operation of a foot treadle is avoided. Also, finished slates are piled in portable racks mounted on wheels. The filled racks are hauled to the storage yard by gasoline locomotive, horse, or other means. Thus, arduous rehandling of slate is avoided. Waste from both trimmer and splitter falls down slides into cars on depressed tracks and is conveyed to a dump, or it may be carried continuously with a belt conveyor.

"Architectural" Slates.—The preceding paragraphs on roofing slate deal exclusively with standard types three sixteenths to one fourth inch in thickness. Until recent years only smooth slates of uniform size and color have been in demand, but modern architectural taste calls for increasing quantities of rough-textured slates, graded in size and of variable and mottled colors. Slates showing contrasting color effects are obtained mainly in the New York-Vermont district, but many textural or "architectural grades" are produced in other districts. Variations in

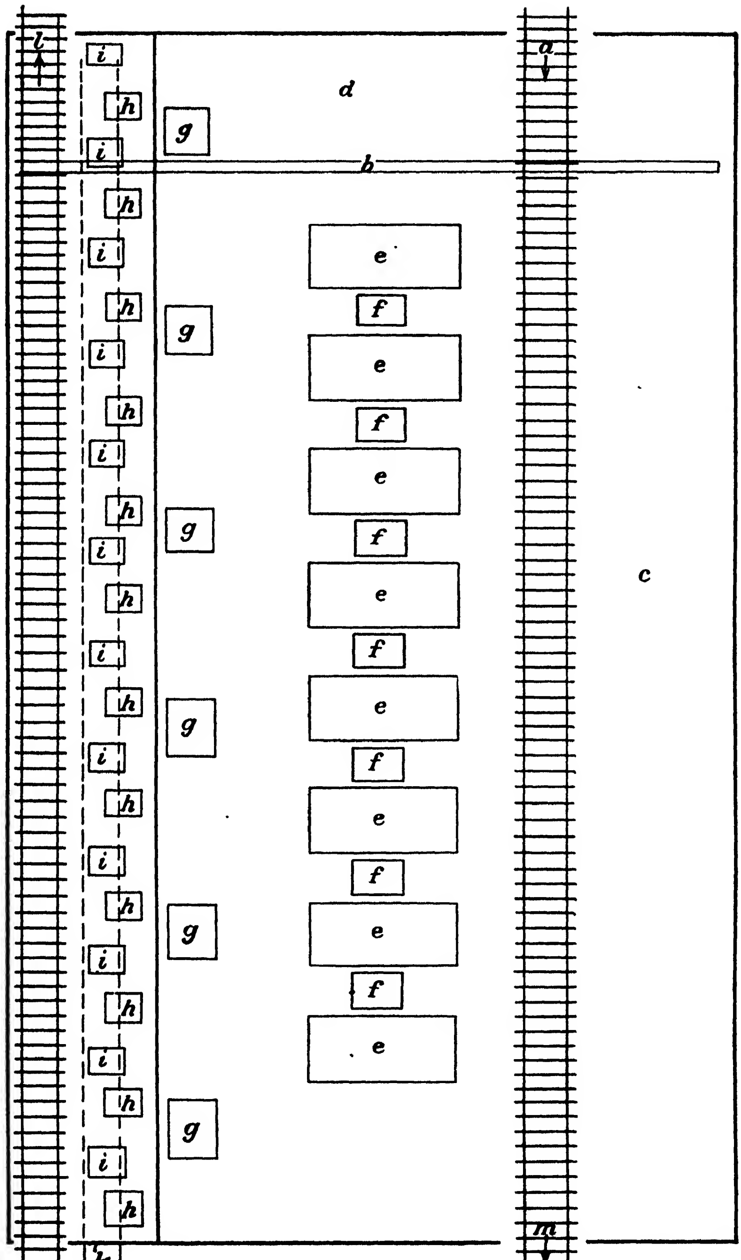

FIG. 53.—Plan of roofing slate mill. *a*, track for slate blocks; *b*, traveling crane; *c*, *d*, block storage; *e*, saw beds; *f*, boxes for waste; *g*, blockmakers; *h*, splitters; *i*, trimmers; *k*, belt conveyor for waste; *l*, track for portable slate rocks; *m*, track for waste.

sizes, colors, and surface finish produce rustic effects that are very attractive, particularly in large structures. The demand for slate of this type has been advantageous to producers. No substitute materials have been found that provide the rustic effects of the natural slates, and therefore this branch of the industry has grown rapidly. Furthermore, large, heavy slates, some of them 1 to 2 inches thick, may be manufactured from beds where the material has too poor a cleavage for manufacture into standard-grade roofing slate, and more complete utilization of quarry rock is possible. Special types of powerful trimming machines are employed to dress massive slates. The knives are constructed purposely to make wavy, irregular outlines.

STORAGE OF ROOFING SLATE

Finished slates are piled on edge in storage yards, and each pile comprises slates of the same size. They are placed in a nearly vertical position and usually are stacked not more than three tiers high (see figure 52). As a rule, slates are punched for nailing before shipment. A punching machine, operated by a foot treadle or motor, punches two holes simultaneously. The side uppermost in punching is placed downward on the roof, for the punch makes an inverted conical hole, the larger part of which provides a ready means of countersinking a nail head. Slate too thick to punch and some thin slates on special orders are drilled and countersunk, usually with motor-driven rotary drills.

THE ART OF ROOFING WITH SLATE

To endure for many years a slate roof must consist of high-grade material free from cracks or other defects. The units must be of standard thickness and proper manufacture, with the grain parallel to the long axis. Part of the responsibility for a good roof rests however with the roofer, for excellent-quality slate may make a leaky roof if improperly placed. That any carpenter can lay slate is a common statement, and many roofs are laid by inexperienced workmen, but they give much better service when placed by men who specialize in such work. For example, in placing slates most carpenters drive the nails "home," just as they would in securing wooden shingles, with the result that if the sheeting dries and shrinks the slates are cracked. A skilled slate roofer does not drive the nail to its full depth, but allows the slate to hang loosely.

Another common error is due to mistaken economy or even dishonesty on the part of a roofer who to save slates may give a head lap less than the regulation requirement of 3 inches. As a result the roof may leak, not through any fault of the material, but because of improper workmanship. The law in some States renders it illegal to place slate with less than a 3-inch head lap. Nails and other metal work used in conjunction with slate should be durable.

MANUFACTURE OF SCHOOL SLATES

Slate suitable for the manufacture of school slates is found in soft, black beds free of all hard streaks or knots of flinty material. The rough blocks are split in the same manner as roofing slates, but trimming is done with small saws rotating at high speed. The shape of one type in common use is shown in figure 54. When trimmed to size they are delivered to school-slate factories. Here the edges are first beveled; then the slate is placed on edge between two knives, and a descending bar forces it down, so that the knives scrape off all rough projections. A second pair of knives gives a smoother surface. The slates are then polished between sanded drums, thoroughly washed in hot water, and carried on a belt conveyor through a heated chamber for drying before being piled. They are then ready for framing. Slates broken in framing are unframed and recut to smaller sizes. Several million school slates are manufactured in the United States every year, and about 90 per cent are exported.

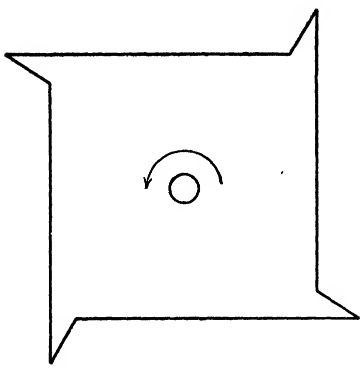

FIG. 54.—Type of rotary saw used for trimming school slates.

MANUFACTURE OF MILL STOCK

The term "mill stock" includes all forms of structural slate, such as steps, wainscoting, baseboard, lavatory enclosures, and mausoleum crypts, as well as billiard tables, grave vaults, blackboards, and electrical panels or switchboards. The chief processes within the mill are hoisting, sawing, planing, edging or jointing, rubbing, and buffing or polishing. Mills usually are close to quarries and are in the form of long closed sheds. Slate blocks are brought from quarries on cars hauled by gasoline locomotive or some other means. Derricks are provided for handling blocks and waste, but some newer mills have overhead traveling cranes of 5- to 10-ton capacity.

Sawing.—Quarry blocks are measured and marked in accordance with the products to which they will cut to best advantage. A marked block is placed on a saw bed, which is propelled back and forth by a pinion working in a rack of cogs. Different rates of travel are made possible by a system of gears. The slow speed may be not more than 3 inches a minute; when thinner or softer slate is cut a bed may travel 20 inches a minute or faster. The belt which drives the saw runs on a cone of pulleys; thus different rates of rotation may be obtained, and the desired speed is governed by the nature of a slate block. An average

rate is six or seven revolutions a minute. Saws range from 24 to 48 inches in diameter and are about ⅜ inch thick. The teeth are so widened that a saw makes a cut about ¾ inch wide. Ordinarily the saw tooth is part of the blade, but an inserted tooth saw is used where flint knots or pyrite crystals are liable to break teeth. Some experimental work has been done with tungsten carbide-tipped teeth, but such saws are not yet used commercially.

Gang saws are employed to a limited extent in Vermont in slate regarded too hard for circular saws. They are the same in principle as gangs described in the chapter on limestone, except that the blades are only about 6 feet long. Steel shot are used as abrasive.

Experiments are contemplated with the view of adapting wire saws for reducing mill blocks.

Disposal of Sawed Blocks.—After sawing is completed the next step in manufacture depends upon the purpose for which the slate is to be used. When clear blackboard stock is obtained the block is hoisted from the saw bed and leaned against a wooden or concrete pedestal. With hammer and thin flexible steel chisels it is split into slabs about one half inch thick. Slate with a straight split is in great demand, for if a curved or twisted surface is obtained the finishing process is expensive, as much slate must be worn away to reduce the surface to a perfectly uniform plane. Finishing processes are described in later paragraphs. For other forms of mill stock, sawed blocks are split to approximate thicknesses desired and placed on planer beds.

Surface Finishing.—Planing is the first step in surface finishing. The tool—a heavy blade set horizontally and adjustable laterally and vertically—planes the surface of a block as it is carried back and forth on a traveling bed. With each motion the tool is moved laterally until it has passed over the entire surface. If all irregularities are not removed the tool is set at a lower level and the block replaned. It is then turned over so that the smooth surface rests on the bed, and the opposite side is planed in the same manner, but special care must be taken to obtain the desired thickness for the finished product. A block is not reduced to its final thickness in a planer, for some allowance must be made for removing slate during subsequent processes, such as rubbing or honing. Blackboards are planed only when they are uneven or have a curved split. For rougher forms of structural slate, such as grave vaults, planing gives the final surface finish.

For a smoother finish slabs are placed on rubbing beds similar to those used in marble and sandstone mills. They consist of cast-iron disks 12 or 14 feet in diameter which rotate in a horizontal plane with the slate slabs resting on the upper surface. A stream of water is constantly supplied, and sand is used as abrasive. A rubbing bed is not only used to obtain a smooth surface but also to grind rectangular blocks to size. An

operator uses a gage and square and thus can turn out blocks true to size and having right angles. A rubbing bed also is used for making beveled edges on switchboards and other products, though often a coarse file, pneumatic tool, or Carborundum wheel is used for this purpose.

Certain products, such as blackboards and switchboards, require a much smoother finish than is obtainable on a rubbing bed. A fine polish or honed finish may be obtained with a belt or drum sander, a buffer, some other form of polishing machine, or by hand. A buffer, which is most commonly used, consists of two movable arms; one attached to the end of the other, holding a rotating buffer head. The latter is belt-driven, with one belt for each arm, and the pulleys are so adjusted that their axes coincide with the axes of rotation of the arms; thus, the polishing head may be moved about to any desired position without interfering in any way with the movement of belts. The rotating head is fitted with a set of six or seven blocks set in plaster of paris and consisting of polishing materials made up in accordance with various formulas worked out by mill operators. A stream of water is directed on the surface, and the rotating head is moved back and forth until a fine polish is obtained. A special type of multiple-head polishing machine, consisting of a series of six rotating arms, each with a polishing block, has been devised to take the place of a buffer. The circles overlap, and the arms are so adjusted that blocks follow each other over the same ground with no interference. A slab of slate to be polished is placed on a traveling bed which conveys it back and forth beneath the rotating arms. In some mills blackboards are finished by hand methods with steel scrapers and polishing blocks.

Through the use of drum sanders instead of rubbing beds and buffers a noteworthy advance in surface finishing has been accomplished by a Maine slate company. Paper-backed silica sandpaper is wound spirally on drums, three drums are arranged in series, and slate slabs are passed beneath them on a traveling rubber-covered bed. First, coarse grit is used to bring down the surface to fair uniformity and smoothness, and for finishing finer grits are used. A drum sander is several times faster than a rubbing bed and may with further development also replace planers.

Carborundum machines are used widely to cut cove base and floor tile, to cut bevels or grooves, to trim blackboards, and to recut slabs to smaller sizes. The bed carrying the slate slab is stationary, and the rotating wheel travels back and forth. The machine cuts rapidly and accurately and leaves a very smooth surface.

Drilling Holes.—Electrical companies using switchboards commonly drill them for wiring, but sometimes this is done at slate mills. Extreme accuracy is demanded, as to both position of holes and workmanship. One mill in Maine uses a spindle drill which can bore 16 holes at once. The spindles that hold the drills are flexible and so may be adjusted to position. A pattern or template is used through which the drills mark the

slate block. The template is then removed, and the drills are guided accurately by the depressions thus formed.

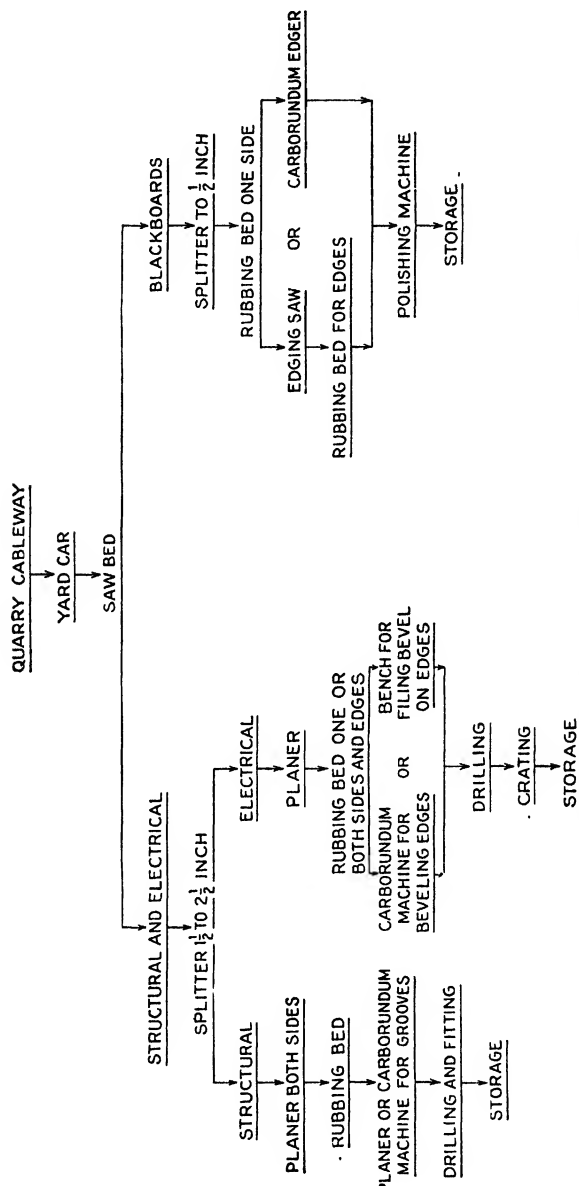

Fig. 55.—Flow sheet of a mill for manufacturing structural and electrical slate.

Storage.—Blackboards, electrical slate, panels, steps, and other structural forms usually are stored at the finishing end of the mill. Racks are provided where all slabs may be placed on edge, for thus each one is available when needed.

Flow Sheet of Slate Mills.—The machines in a mill should be so arranged that the slate passes most directly from one to another, for much time and labor are saved thereby. The normal order of operations in slate manufacture is shown in the flow sheet, figure 55. A plan of a typical mill arranged for convenient operation is shown in figure 56. Slate blocks are brought from the quarry into the mill on track *a*, track *b* being used for removal of waste. Blocks are handled by derricks *c*, between the tracks. Saws, *d*, are arranged down one side of the mill and planers, *e*, down the other side. After the preliminary stages of sawing and planing, slabs are finished in the three wings, as shown at the left. Each wing has a rubbing bed *f*, near its entrance followed by a series of finishing machines, such as Carborundum bevelers, recutters, and polishing machines, as shown at *g* and *h*. Each wing may be devoted to a particular product; for example, one may be used for blackboards, one for electrical slate, and a third for structural slate. A railway siding at the ends of the wings provides a ready means of shipping mill products. An important feature of the mill is the facility with which it permits expansion. If increased capacity is demanded it may be extended and one or more additional wings added, as indicated by the dotted lines in the figure, without interfering in any way with the logical order of machine arrangement.

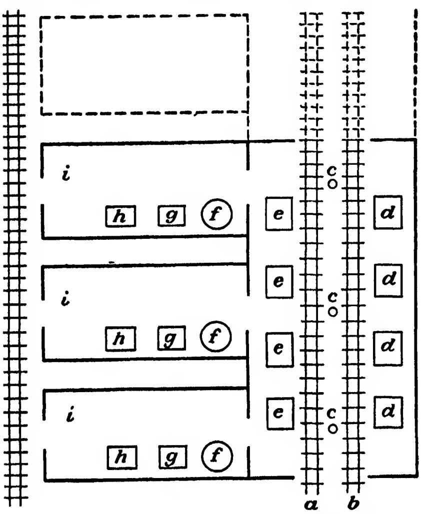

Fig. 56.—Plan of a well-designed slate mill. *a*, *b*, mill-car tracks; *c*, derricks; *d*, saws; *e*, planers; *f*, rubbing beds; *g*, *h*, Carborundum machines, polishing machines; *i*, space for storage and crating.

Marbleizing Slate.—For ornamental switchboards, mantels, and certain other interior decorative products architectural taste sometimes demands a finish other than the natural slate surface. Repeated painting and baking to simulate verde antique, bloodstone, or well-known marbles, is known as "marbleizing." The following is a typical process. The slabs first are painted black, then baked several hours in a chamber heated to 175°F. They are then dipped in a trough of water having red, white, and green paint floating on the surface. A skilled operator can stir the water in such a manner as to obtain various patterns with the floating paint. When a slab of slate is brought into contact with the surface the paint adheres and reproduces a pattern. It is baked a second time, varnished, baked a third time, polished with pumice, and finally baked a fourth time. This gives a "bloodstone"

finish. If no green paint is used a "Venetian" finish results. Checkerboards, flags, and various other designs also are made by this process.

"Struco" Slate.—A later development in surface decoration of slate, to which the trade name "Struco" has been applied, involves processes that are quicker and less expensive then marbleizing. Color patterns are applied as lacquers with a nitrocellulose base and a volatile hydrocarbon as the vehicle or solvent. Unlike a paint, the drying and hardening are brought about by evaporation rather than oxidation. A slate slab first is polished with a belt sander or buffer. The lacqüer is then applied to the surface with a spray nozzle operated with compressed air. The highly volatile solvent evaporates in 15 or 20 minutes, leaving a firm, hard surface. A pattern is then applied over the base coat by a printing process. A copper plate is engraved as a photographic reproduction of an attractive veined marble. Lacquer is applied to the plate, and when a soft-rubber roller is passed over it and then over the slate surface the pattern is transferred in every detail. A transparent surface coat is then applied; and, after hardening, it is carefully polished. Struco slate is unaffected by sudden changes of temperature or by hot or cold water and is highly resistant to chemicals. Moderately decorative surface finishes are in demand for shower stalls and wainscoting, while the more ornamental types are used for table tops, radiator covers, lamp bases, smoking sets, clocks, and various novelties. Struco products are not designed to replace slate in its legitimate field but rather to find use in places where colors other than the natural shades are desired.

SLATE FLOORS, WALKS, AND WALLS

Ornamental flagging is becoming increasingly important. Slate with a honed finish and very close joints makes a beautiful floor. Material from different regions permits floor designs in color patterns that vie in beauty with the most ornate rugs and have the added value of indestructibility by fire, water, or continuous wear. For paving yards, porches, courts, roofs, or ornamental walkways, rough-textured, natural cleft slates are employed. Two main styles are in general use. The "regular" style consists of rectangular flags of various sizes and colors fitted together with close joints; the "irregular" is made of random shapes and sizes that are necessarily less closely fitted and require well-cemented joints.

Slates of various colors are being used as wall stone in such structures as churches and college buildings, particularly in conjunction with other kinds of stone, to produce variegated effects in color and texture.

CRUSHED AND PULVERIZED PRODUCTS

Slate crushed to sizes comparable with grains of fine gravel is known commercially as "granules," the manufacture of which has developed into an important industry. Granules range in size from 10- to 30-mesh

and are used to coat various forms of tar roofing. Although most granules consist of slate, other materials, such as trap rock, shale, and serpentine, are also used. The industry is, with few exceptions, distinct from the manufacture of roofing slate; it is, in fact, a competitor, for large quantities of slate-surfaced roofing are now being sold for use not only on sheds, garages, and other inexpensive structures but also on moderate-price dwelling houses of a class commonly roofed with slate. Although slate quarry waste is ground and pulverized to a limited extent most plants making granules and flour operate quarries exclusively for these purposes, and in nearly every instance the rock is unsuitable for roofing or mill stock. The types of crushing and grinding equipment used vary widely. Where a plant is erected primarily for making granules, the purpose is to crush with a minimum production of fines, which are discarded largely as waste, but where there is a good market for pulverized material a large proportion of fines may not be regarded as a disadvantage. Even where the same type of product is desired no two grinding plants are alike. Variations are due to differences in raw materials, amount of capital available, and varying opinions regarding efficiency of machines. A flow sheet of a typical mill using waste from a large Pennsylvania quarry which produces both roofing and mill stock is shown in figure 57. The mill is electrically driven with individual motors for each machine and produces both granules and slate flour.

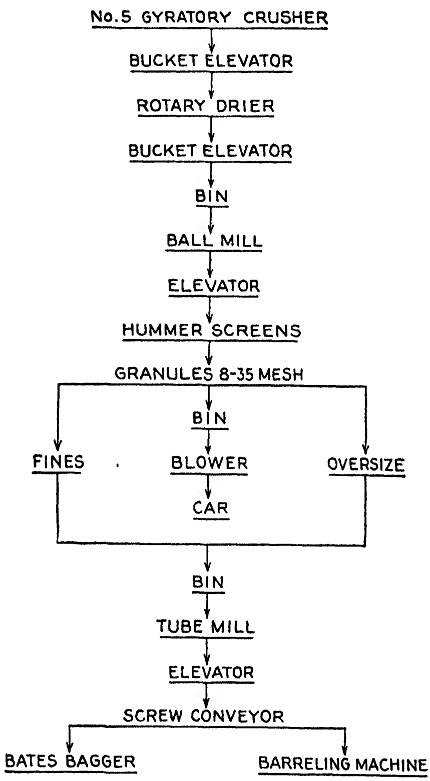

FIG. 57.—Flow sheet of a mill for manufacturing slate granules and slate flour.

WASTE IN QUARRYING AND MANUFACTURING SLATE

An outstanding feature of the slate industry is the high proportion of waste. It is reported that in one large quarry in Vermont about 15 tons of waste rock are removed for each ton of roofing slate recovered. In most regions waste averages 70 to 90 per cent of gross production; in

other places, particularly in underground mining, it may be as low as 50 or 60 per cent. In Wales 1 ton of slate is said to be produced for every 8 tons of waste rock quarried.

Waste is due to a variety of causes. Slate occurs in beds commonly termed "veins" by quarrymen, though they are not veins in the sense in which the term is used geologically. Beds of inferior rock alternate with the good beds, and because of their intimate association the former must often be removed to secure the latter. Furthermore, only part of the good beds may be used, for much must be discarded because of such imperfections as siliceous knots, ribbons, and cracks. A considerable percentage also is lost in the process of removal; blasting may shatter it, or irregular fractures caused by wedging may result in loss. A further heavy percentage of waste results from the manufacture of roofing slates, and great quantities of refuse must be removed from beneath the saws and planers of a structural slate mill.

Slate quarrymen have approached the problem of waste from two angles. The first involves modifications in methods and machines whereby a substantial reduction in the percentage of waste may be attained; the second concerns various ways in which waste slate may be utilized.

Prevention of Waste.—Slate is subject to many natural imperfections over which a quarryman has no control. If only 40 per cent of the mass of rock blocked out in a quarry is usable, 60 per cent is the lowest minimum to which waste may be reduced, even in theory. In actual practice the proportion of waste must exceed 60 per cent by varying amounts depending on the efficiency of quarrying and manufacture. If the final product constitutes only 15 per cent of gross production and 85 per cent is waste, obviously 25 of the 40 per cent, or five eighths of the good slate, is wasted in quarrying and manufacture. A certain percentage of the good rock must necessarily be lost in these processes, but whatever share of this five eighths may be saved by improved processes or equipment may be termed "preventable waste."

Much thought and experimenting have been devoted to ways of reducing the proportion of waste. A first step is to plan development systematically in conformity with rock structures. The imperfections of slate and joints, ribbons, or other structural features can not be changed, and the most orderly quarries are planned to minimize their effects. A second step in conservation is care in the use of explosives. Much waste results in some quarry regions from excessive blasting, because the belief prevails that no other means can be used successfully for separating primary rock masses. In other regions much more economical methods have been worked out. Wire saws now widely used in Pennsylvania have reduced waste in amounts ranging from 25 to 50 per cent of the proportion under former processes. Channeling machines are

a great improvement over blasting methods, and wire saws represent equal advancement over channeling.

Utilization of Waste.—Owing to imperfections of rock and the inevitable loss of material in quarrying and manufacture, a large percentage of the gross production of slate quarries must be considered waste, even under the most efficient quarrying and manufacturing methods. The need for some useful outlet for waste slate has been felt for many years. Various investigators have given attention to the problem, but results have had little practical value. Slate consists of silicates that have few uses compared with some other rocks. For example, limestone may be used for lime and cement manufacture, agricultural purposes, and furnace flux; while slate is unsuitable for these purposes. Its commercial adaptability is, therefore, greatly restricted, and on this account all but a very small fraction of the waste accumulation since slate was first quarried is still lying in veritable mountains awaiting possible utilization.

Some years ago interest was centered in a Welsh enterprise for the conversion of great quantities of waste slate into useful products. Extravagant claims were made and the plant was operated for a short time, but the enterprise failed; however, some progress is being made in waste utilization in Great Britain.

Uses of Waste in Massive and Granular Form.—Waste slate from splitting shanties was at one time cut into 3- by 6-inch rectangles, set in mastic on a backing of prepared roofing, and sold for use on flat roofs under the name "inlaid slate." One plant operated from 1905 to 1917, but there has been no production since. Waste slabs have been manufactured into perforated-slate lath and veneer. The latter product, which was used for interior walls, consisted of a thin slab of slate attached to gypsum board. These projects never advanced beyond the experimental stage.

Manufacture of granules for slate-surfaced composition roofing has developed into an important industry, but, as stated previously, only a small fraction of the raw material is waste from slate quarries or mills.

Waste Slate as a Filler.—Waste rock from mills and quarries is used to some extent pulverized. Many products, such as paper, rubber, road asphalt, floor coverings, and paints require as one of their important constituents a considerable percentage of finely pulverized inert mineral matter to give "body," to obtain desired consistency, or to supply the necessary wearing or other qualities demanded. Such materials are known as "fillers." Slate dust is a satisfactory filler in many such products.

To encourage wider use of waste slate the United States Bureau of Mines in 1920 and 1921 cooperated in experiments with about 45 industrial firms. The cooperating companies were manufacturers of rubber products, linoleum and oilcloth, road asphalt, and plastic roofing.

Plant and laboratory tests with samples of slate flour were conducted, and results were submitted to the bureau for compilation. It was found that finely pulverized slate is a satisfactory filler for mechanical rubber goods but not for the higher grades of rubber, such as are used in automobile tires. Slate flour gives good service as a filler in linoleum, oilcloth, and window shades, except where white is desired. It is well-adapted for filler in plastic roofing and flooring, and several hundred carloads are so used every year.

Tests in laboratories of companies preparing road-asphalt mixtures indicate that for resistance to impact slate flour about equals other fillers in bonded briquets and is somewhat superior in sheet-surface mixtures. In cementing value it was found to be superior to both limestone and portland cement in asphalt-bonded briquets and intermediate between them in standard sheet surface mixtures. Elutriation tests indicate that slate flour contains approximately 15 to 25 per cent more fine dust that constitutes effective filler than limestone, trap rock, or portland cement. In low weight for a given volume—a desirable feature of a filler,—slate is about equivalent to limestone and approximately 10 per cent superior to portland cement. Slate flour is therefore an exceptionally good filler for road asphalt-surface mixtures.

Ground slate has been used in various ceramic products, but no conclusive results have been obtained. On account of its low fusion point it has some possibilities as a glazing material. Considerable quantities of finely pulverized slate are consumed as paint filler. Producers of slate flour in cooperation with consuming industries have developed many uses in minor products.

It is evident, therefore, that slate flour may be employed in quite a variety of ways, and some consuming industries are actual or potential users of large quantities. However, slate flour, like granules, is produced in very small amount from slate waste; most of it is derived from quarries worked exclusively for crushed and pulverized products.

TESTS AND SPECIFICATIONS

The grading of roofing slate varies in different localities. In the Bangor district of Pennsylvania slates are graded as No. 1, clear; No. 2, clear; No. 1, ribbon, where the ribbon is not exposed on the finished roof; and No. 2, ribbon, where it is exposed. They are graded similarly at Pen Argyl, Pa., with omission of No. 2 ribbon. At Slatington, Pa., and in Vermont they are graded as No. 1, No. 2, and intermediate. Peach Bottom slates are graded as No. 1 and No. 2. The Virginia product is known in the trade as Buckingham slate and graded as No. 1 and No. 2. Heavy, rough types are known as architectural grades.

To establish more uniform and definite grading the Federal Specifications Board has framed a specification for roofing slate to be used by

Government departments. Three grades, designated A, B, and C, are based mainly on strength, absorption, and depth of softening when immersed in an acid bath. The specification was published as of July 26, 1932.

Much valuable information on types of roofs, method of laying, slope, gutters, flashings, snow guards, and other data a slate roofer should know are given in an illustrated booklet, "Slate Roofs," issued in 1926 by the National Slate Association.

Structural slate is graded as ribbon or clear in Pennsylvania and according to color in Vermont. A series of pamphlets on data and standards, issued by the Structural Service Bureau of Philadelphia, has accomplished much in simplifying manufacture, in assisting architects and builders to place orders for structural slate quickly and easily, and in making it possible for manufacturers to fill orders promptly from standard sizes kept in stock.

The requirements for electrical slate are more rigid than for structural or roofing slate; in addition to easy workability it must have high dielectric strength and must therefore be free of all ribbons or other conducting materials. No definite specifications have been established, although much progress has been made in perfecting testing methods.

Slate granules generally are limited in size between 10- and 30-mesh. Equidimensional rather than flat grains are preferred. Fines are rigidly excluded; the percentage allowed usually is so low that granules in storage ordinarily are air-cleaned while being loaded to remove the fines produced in handling.

No generally used specifications have been adopted for slate flour as it is used in many different products which have varied requirements. Manufacturers of similar products differ widely among themselves in size requirements for fillers. Producers of slate flour are obliged to modify their milling equipment to satisfy the demands of individual customers.

MARKETING

Consideration of the uses of slate makes it evident that the chief consuming industries are the building trades and manufacturers of electrical equipment. As building construction is a nationwide industry, the chief centers of consumption are fixed largely by freight rates, building programs, and the activity of selling agents. Roofing slate is used widely on buildings east of the Mississippi River, but because of former high freight rates the demand west of the Mississippi was limited. Recently rail-water rates have been reduced, and increasing quantities of slate are reaching Pacific coast points by way of the Panama Canal. Likewise, reduction of rates is opening up extensive markets south of the Carolinas, where little slate has been used except in New Orleans. Here the necessity for conserving the rain-water supply has encouraged the use

of insoluble, sanitary slate roofs. Structural slate is less affected by freight and thus has a somewhat wider market than roofing slate.

The centers of electrical slate consumption are the large eastern and middle western industrial cities, such as New York, Boston, Philadelphia, Schenectady, Pittsburgh, Chicago, and St. Louis. The market for blackboards is general throughout the United States and Canada. Most school slates are exported. A marked growth in use of slate for floors and walks has been evident since 1925 and is rapidly spreading over the entire country, because the pieces are classed as "scrap" slate and are carried at lowest freight rates. There is a scattered demand for slate blackboards and for structural slate in the insular possessions of the United States and in Cuba.

The chief marketing points for slate are Pen Argyl, Bangor, Slatington, Easton, Bethlehem, Philadelphia, and Delta, Pa.; New York City; Monson and Portland, Me.; Boston, Mass.; Granville, N. Y.; Poultney and Fair Haven, Vt.; and Richmond and Norfolk, Va. There are practically no seasonal fluctuations in the demand for electrical slate, but owing to building inactivity the demand for structural, roofing, and scrap slate is somewhat restricted in winter. Subnormal demand for blackboards usually is in evidence during March, April, and May.

The slate industry has very difficult marketing problems. Lack of more consistent growth in the industry is to be attributed chiefly to the keen competition slate must meet in every line of consumption. Various types of roofing are advertised much more widely, and many are synthetic products that can be manufactured at low cost. Similarly, slate meets much competition in structural and electrical applications.

Lack of efficient selling and advertising agencies also retards effective marketing; those sections of the industry that are most inactive in this respect are the least prosperous. There is, however, evidence of a movement toward bettering this condition through establishment of joint marketing agencies in some localities to bring about better contacts between producers, distributors, and roofing and setting contractors, thus promoting sales and insuring better service to ultimate consumers. The outstanding problem in all slate regions is to find a large enough market to absorb the normal output of the quarries. Marketing companies and associations are exerting a growing influence, particularly in Pennsylvania and Virginia. Sales organizations in Vermont and New York have been effective only in marketing structural slate and that used for floors, walks, and walls. Those who have the best interest of the industry at heart contend that excellent service under the most exacting requirements will enhance the salability of the products. Expansion of markets therefore depends to quite a degree on proper classification of slate and on the diversion of each type to the use for which it is best adapted. This requires an exact and intimate knowledge of properties and qualities,

and to obtain the necessary fundamental data the National Slate Association and Committee D-16 of the American Society for Testing Materials are sponsoring studies of properties and methods of tests. The United States Bureau of Standards and several college laboratories, notably those of Lafayette College, Lehigh University, Pennsylvania State College, Rensselaer Polytechnic Institute, and Massachusetts Institute of Technology, are collaborating in these studies.

Persistent price-cutting, even at levels below the cost of production, has characterized slate marketing. As this is due in a measure to an insufficient knowledge of quarrying and milling costs an effort has been made to establish better and more uniform cost keeping, and a cost-accounting system for the industry has been published.[38]

Structural slate is sold to slate-setting contractors. Roofing slate is sold to roofers and building-supply dealers through jobbers or brokers or directly by quarry operators. To lessen breakage and prevent reducing the requisite 3-inch head lap, nail holes for attachment of the slate usually are punched before shipment.

Slate flour, granules, and scrap are sold by the ton, though scrap used for floors and walks sometimes is figured in superficial feet. Granules are sold in bulk in carload lots direct to manufacturers of composition roofing. Slate flour is disposed of to paint manufacturers and marketed in small amounts to miscellaneous users, such as manufacturers of roofing mastic, rubber, and linoleum. It usually is sold in paper bags or wooden barrels but may be marketed in bulk to large consumers. Roofing slate sells by the square (enough to cover 100 square feet when placed on a sloping roof with standard 3-inch head lap), mill stock and blackboards by the square foot, baseboard by the running foot, and school slates by the dozen.

IMPORTS AND EXPORTS

Slate imports range from $50,000 to $130,000 in annual value. There are fluctuations from year to year, both in total and in relative amounts from different countries. During recent years the chief sources of foreign slates have been Italy, France, Portugal, Norway, and the United Kingdom. About 15 per cent by value in 1929 was roofing slate. The remainder was made up of blackboards and of slabs and other products not clearly specified.

From 1925 to 1929 annual exports of roofing slate ranged from 5,000 to 10,000 squares a year and had an average value of $9 to $12 a square. Between 75 and 85 per cent were sold in Canada. Exports of other slate products over a period of years are shown in the following table compiled by the United States Bureau of Mines:

[38] Bowles, Oliver, A System of Accounts for the Slate Industry. Rept. of Investigations 2971, Bureau of Mines, 1929, 25 pp.

SLATE OTHER THAN ROOFING EXPORTED FROM THE UNITED STATES, 1929–1930 AND 1936–1937 BY USES

Use	1929		1930		1936		1937	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
School slates, cases*	19,570	$108,135	16,280	$ 95,935	2,651	$ 20,204	4,434	$ 35,011
Electrical slate, square feet......	16,720	18,037	18,830	20,406	5,528	4,449	3,986	2,356
Blackboards, square feet......	188,720	74,610	177,760	59,810	53,486	15,502	26,033	6,853
Billiard tables, square feet	20,150	34,455	15,760	9,802	26,729	10,601	30,443	16,580
Structural, square feet............	18,390	15,882	12,670	5,280	25,592	5,831	26,462	4,393
Slate granules and "flour," short tons	14,250	84,185	27,540	162,000	9,412	67,012	11,184	77,576
	....	$335,304	....	$353,233	....	$123,599	....	$142,769

* Cases weigh 130 to 165 pounds each; average is 135 pounds.

Practically all exports of roofing slate and granules, over 95 per cent of the structural, and over 50 per cent of the electrical slate were shipped to Canada in 1929. School slates also were shipped to Canada; but India, Netherland East Indies, Australia, and New Zealand took the largest quantities in 1929. South America, West Indies, and Asia furnished markets for electrical slate; and Mexico, Central America, and the Philippine Islands for billiard-table slate. The above data are typical of the export trade in any year.

TARIFF

Before 1913 the duty on imported slates, chimney pieces, mantels, slabs for tables, roofing slates, and all other manufactures of slate was 20 per cent ad valorem. The act of October 1913 reduced it to 10 per cent; that of September 1922 raised it to 15 per cent; and the act of 1930 raised it to 25 per cent ad valorem.

PRICES

Roofing-slate prices are quoted at times in trade magazines, though many sales are made by individual bargaining at prices that may diverge widely from those quoted in the market columns. The price per square varies with the size, and the larger sizes command higher prices. The average selling price of all kinds in 1929 was $10.65 a square. In 1932 it was $7.43 a square.

Mill products are not quoted regularly, but list prices are supplied to customers. The average selling price a square foot for the various

products in 1929 was as follows: Electrical, 80 cents; structural, 40 cents; vaults, 26 cents; blackboards, 30 cents; billiard-table tops, 40 cents; and flagging, 10 cents. Granules and slate flour sold at about $5.80 a ton. The above figures are based on selling prices at the quarry or mill. Prices were somewhat lower in 1930, 1931 and 1932.

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CHAPTER XI

SOAPSTONE

Production of soapstone is commonly considered part of the talc industry, as talc is a constituent, but the uses of these commodities are for the most part quite diverse, because at least 95 per cent of all talc produced is sold pulverized while a large proportion of all soapstone quarried is sold as blocks of various shapes and sizes. Soapstone is used widely in construction and for building accessories, therefore it may properly be called part of the dimension-stone industry.

COMPOSITION AND PROPERTIES

The term "soapstone" in its original sense apparently was synonymous with steatite or massive talc; however, it more properly includes all dark gray to greenish talcose massive rocks which have a soapy feel and which with few exceptions, are soft enough to be carved easily with a knife. Nearly all soapstone produced for commerce is metamorphic rock containing 10 to 80 per cent talc, a hydrous magnesium silicate of composition expressed by the formula $H_2Mg_3(SiO_3)_4$. The most characteristic physical properties of talc are its softness (it may be scratched easily with the finger nail) and its soapy feel. Although talc is the most characteristic, and frequently the chief, constituent of soapstone other minerals are present in varying amounts; chlorite, amphibole, pyroxene. and mica are the more common constituents, with smaller amounts of pyrite, quartz, calcite, and dolomite. Soapstone must therefore be regarded as a rock rather than a mineral; and because of its variable composition, its hardness and strength are also variable.

HISTORY

Soapstone was carved into ornaments by the ancient Egyptians and Assyrians, and for many centuries the Chinese have used it for the same purpose. It has long been used in limited quantities as a building material. The cathedral of Trondhjem, Norway, is built of soapstone from Gudbransdal.

Soapstone was first used in the United States by the American Indians, who, recognizing its heat-retaining qualities, shaped it into bowls, pots, cooking stones, and other objects now on display in many museums. The term "potstone," which is still applied to soapstone in some localities, originated from these early uses. Deposits in Albemarle

County, Va., were opened on a semicommercial scale about 1880. During later years the industry migrated into Nelson County, and recent activity has been confined to the vicinity of Schuyler. A small production has been noted at various times in Maryland, North Carolina, Rhode Island, Vermont, and California, but Virginia has always dominated the industry. A quarry near Marriottsville, Md., was reopened in 1933.

During recent years so much of the production has been in the hands of a single company that figures can not be published without revealing individual statistics. However, the following table, compiled from United States Geological Survey publications, is presented as a record of output for a number of years.

Domestic Soapstone Sold in the United States, 1916–1924

Year	Quantity, short tons	Value
1916	19,127	$ 489,606
1917	19,885	402,506
1918	12,330	501,059
1919	16,504	530,163
1920	19,707	709,400
1921	17,423*	627,826*
1922	22,700	712,144
1923	22,857	932,098
1924	25,630	1,288,885

* Sawed and manufactured talc included under soapstone.

USES

The uses of soapstone are related intimately to its physical properties. Its easy workability, light color, and resistance to weathering or water action fit it admirably for many structural purposes; laundry tubs, sinks, aquariums, wainscoting, mantels, baseboards, stair treads, tiles, and spandrels are made of soapstone. Floor tile and steps sometimes are calcined to make them harder than rock in its natural state. Because of its resistance to chemical action and low absorptive properties soapstone is adaptable for laboratory table tops and sinks, hoods, ovens, acid tanks, vats, trays, development tanks for photographs and blue prints, drains, and furnace blocks for lining retorts in paper mills. Some soapstones have high dielectric strength, which, combined with easy workability, makes them desirable for electrical insulation units, such as switchboards, panels, barriers, fuse guards, bases, circuit-breaker compartments, insulating floor slabs, battery-room flooring or shelving, and similar products. Because of its ability to resist and to retain heat, soapstone is employed for griddles, foot warmers, fireless cooker stones,

fireplaces, hearths, and furnace linings; some of these uses, however, are declining.

Soapstone is divided into three grades—soft, regular, and hard. The high heat resistance of the soft grade makes it especially desirable for furnace linings and other uses where high temperatures prevail. The hard grade, containing a large proportion of the harder siliceous minerals, such as hornblende and actinolite, is best suited for stair treads, floor tile, and other products subject to wear. The regular grade, midway in properties between the hard and soft, is by far the most abundant. Virtually all fabricated equipment having interlocking joints, such as laundry tubs, sinks, and sanitary partitions, is made of soapstone of this quality.

Granular soapstone, hardened by heat treatment, is used for surfacing prepared roofing. Pulverized waste material is employed as an admixture in concrete and as a filler and sold to some extent for dusting coal mines.

ORIGIN AND OCCURRENCE

Most soapstone is regarded as an alteration product of basic igneous rocks rich in magnesium. The extensive deposits near Schuyler, Va., consist of irregular or lenslike dikes bordered with mica schist and peridotite. These deposits have been studied and described in some detail, but very little is known of the occurrences in other States. The important deposits in Virginia form a belt which extends through Nelson, Albemarle, and Orange Counties and for many years have constituted the chief source of supply. Small deposits have been noted in Fairfax, Franklin, Amelia, and Henry Counties. Soapstone is quarried near Thetford Mines, Quebec, Canada, for production of furnace blocks and pulverized products.

QUARRY METHODS

The normal size of quarries at Schuyler, Va., is 100 feet long by 100 to 120 feet wide, the width being governed by the size of the dike. Enough soapstone to provide a good face is left in place along the hanging wall. If several quarries are opened on one dike, walls 22 feet wide are left standing between operations. The depth to which a quarry may be worked depends on safety of the walls; the average depth is nearly 200 feet.

Overburden is removed chiefly by steam shovels and drag scrapers, though hydraulic methods have been used. Occasionally good stone is found near the surface, but usually the upper floors are removed as waste. No explosives are used in either waste or good rock. Overburden and waste usually are dumped into pits that have been worked out and abandoned.

A stripped quarry floor is channeled across the strike with steam or electric-air machines. The distance between channel cuts is 4 to 6 feet, and the average depth $6\frac{1}{2}$ feet. After a center row of key blocks is removed all other channeled masses are undercut to their full depth. An undercutter is a reciprocating machine that works like a channeler. In soft rock a Jeffrey longwall undercutter with stellite teeth is used satisfactorily. One end of the undercut mass is channeled across and the end block broken out. The mass is then subdivided by drilling holes parallel to the natural parting planes of the rock, and by splitting with wedges. As the natural grain dips at angles of 30 to 60° blocks are roughly diamond-shaped. An average block is 4 by 4 by 6 feet. Each is graded according to hardness, color, and soundness. Swinging-boom derricks lift them from the quarry floor and place them on cars or stock piles, depending upon current mill requirements.

MILLING PROCESSES

As with other types of dimension stone, sawing is the first step in manufacturing soapstone products. Gang saws, like those used for

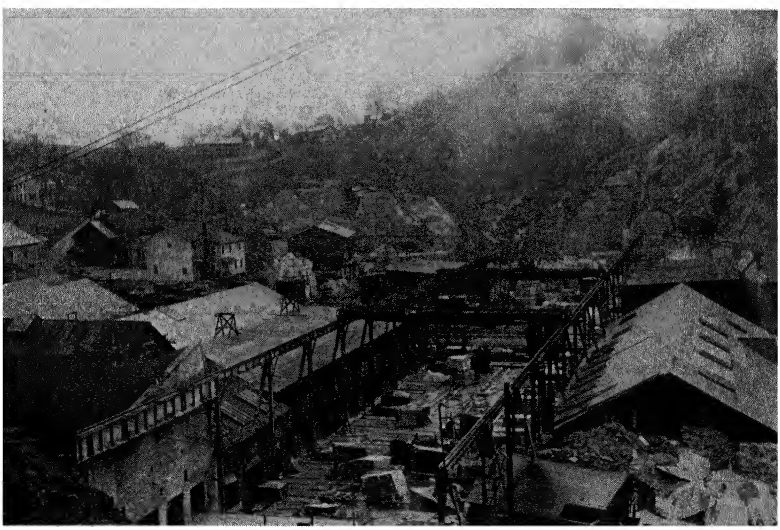

FIG. 58.—Two soapstone saw mills with overhead traveling crane between them, Schuyler, Va. (*Photo by H. Herbert Hughes.*)

marble and limestone, are employed, and 30- to 46-mesh sea sand is used as abrasive. Saws travel back and forth at about 84 complete strokes a minute in the day time, while at night when other machinery is shut down the speed is increased to about 100 strokes a minute. Gangs cut through the stone at about 4 inches an hour. Most of the stock is cut into thin slabs, which results in less waste from oblique-angled blocks than if cubic stock were manufactured. For most uses saw cuts are made

to parallel the grain. Sawed slabs are transferred to either a stock mill or a custom mill. Figure 58 illustrates two soapstone saw mills with an overhead traveling crane between.

A stock mill produces standard products, such as laundry tubs, sinks, and furnace blocks. Trimming is done with a steel-toothed hand saw similar to that used in wood working. The slab surfaces are finished on rubbing beds and tongued and grooved with Carborundum wheels. In assembling tubs one small bolt secures each corner but is not exposed in the interior. All joints are set in cement, consisting of linseed oil, litharge, and whiting, which expands as it seasons, insuring watertight joints. An important function of a stock mill is the manufacture of furnace blocks. These are made in numerous sizes and shapes 3 inches to 3 feet long. Blocks are cut with circular diamond saws, and care is taken that the direction of grain is always at right angles to the exposed surface when a block is set in place; otherwise, it is liable to spall.

All other soapstone, consisting chiefly of structural material, is fabricated in the custom mill according to specifications. The general procedure is similar to that in a stock mill, except that blue prints are followed on all jobs. Furthermore, much stone used in the custom mill is harder than that employed for laundry tubs or furnace blocks. Therefore, circular silicon carbide saws are used instead of hand saws for trimming, and Carborundum grinders supplement rubbing beds. Rubbed slabs pass to a checker, who designates from blue prints the additional fabricating to be done. Completed slabs are assembled in the mill or on the job, depending on the nature of the order.

Some higher-grade waste soapstone is pulverized as filler, chiefly for use in the rubber industry. For this purpose crushers, hammer mills, tube mills, screens, and air classifiers are the chief types of equipment used.

MARKETING

Markets for soapstone are world-wide, but only a small proportion of the production is exported. The largest consumption is east of the Mississippi River, particularly in the Atlantic Seaboard States. The increasing use of soapstone for architectural purposes during recent years has resulted in fluctuations in demand that parallel the seasonal activity of building. Shipments are now made almost entirely by rail and wherever practical in carload lots. Most soapstone products, except furnace blocks, are crated.

There is at present practically no competition within the industry in marketing soapstone. However, it meets with very keen competition from other materials, including marble, slate, sandstone, limestone, and certain synthetic products, in virtually every market except for furnace blocks.

The unit of measurement for manufactured soapstone is a square foot 1½ inches thick. All products, regardless of size, shape, or use, are reduced to this unit. Furnace blocks comprise the largest low-priced output, while complicated development tanks and similar equipment requiring much skilled labor bring the highest prices. Nearly all sales are made direct to builders and contractors; there are no brokers or middlemen.

ROCKS RELATED TO SOAPSTONE

A metamorphic rock known as "greenstone," consisting essentially of actinolite and chlorite, outcrops prominently at Lynchburg, Va. It has an attractive unfading green color that renders it suitable for structural and ornamental building. Many years ago it was used as a local building stone. Basements, chimneys, and entire houses made of it show no evidence of change or deterioration. During recent years the quarries have been reopened, and a mill has been constructed for the manufacture of structural and decorative slabs and other products.

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CHAPTER XII

BOULDERS AS BUILDING MATERIALS

ORIGIN AND NATURE OF BOULDERS

The term "boulders" is applied to loose fragments of rock as contrasted with solid beds or masses, which are designated "rock in place," and is restricted to masses that have become loosened from the parent ledge by natural processes, such as by water, frost action, or glaciation. Boulders usually are plentiful in rugged regions where bedrock is close to the surface and along old shore lines and river beds. They are rare or absent in ancient lake beds that are now land areas or in deltas or outwash plains of rivers, for only the finer, lighter products of rock disintegration are disposed in such places.

A great difference is to be observed between boulders in northern states compared with those in the south. In its southward movement the great ice sheet of the glacial age reached northern New Jersey, central Pennsylvania, and, roughly, a line that followed the Ohio and Missouri Rivers. North of this line most of the surface soil is glacial till, and much of it remains in the condition in which it was left by the ice, though large areas have been re worked and assorted by water action. Materials carried by the ice may have been picked up at widely separated points and carried long distances. Boulders in glacial regions may therefore consist of a great variety of rocks; granites, gneisses, syenites, limestones, sandstones, and conglomerates may all be found within a restricted area. Usually they are rounded and show other evidences of excessive wear.

In the area south of the southern limit of glaciation some boulders may have been transported limited distances by rivers or.other agencies, but for the most part they are of local origin. In limestone regions boulders consist of fragments of underlying limestone; likewise, in granite regions, few, if any, are to be found that are not related directly to outcrops in the immediate neighborhood. Ordinarily they are more angular than those of glaciated regions.

As nature had thus fashioned building blocks and left them conveniently placed on the surface of the ground they probably constituted materials for the most primitive habitations built by ancient races. Their ready availability led to early use by pioneers, and they are still important construction materials.

STONE FENCES

A use of stone of which little mention has been made is as fencing. The subject has been neglected because it falls midway between two great fields of activity—mining and agriculture. A very small part of such stone is quarried rock; nearly all of it consists of boulders picked up by farmers while working in their fields. Employment of stone in this way serves a twofold purpose—clearing land of annoying obstructions and fencing it. Such work must be classed as farm labor; it is not properly part of the mining industry. Compilers of agricultural statistics are interested in the size of fields and mileage of fences but have subdivided fences by kinds to a very limited extent. Hence, for quite logical reasons, no record has been kept of the mileage of stone fences or the amount of material used in their construction.

Most stone fences now in existence were built many years ago. It was necessary for pioneer farmers to clear the land, and labor being cheap, the cost of building stone walls along the borders of fields was not excessive.

Stone has long been a choice material for ornamental walls and fences in town and suburban estates. Since such walls are erected for architectural effect rather than practical value waste rock is used little, but a surprisingly large amount of quarried rock cut into regular dimensions and having a rather high marketable value is so consumed. Walls and fences of this material look so solid and rugged that they are invaluable artistic additions to any home.

Certain objections have been raised to stone fences. Unless well-built, sheep can scale them; they harbor weeds, brush, insects, and burrowing animals; and their removal for the enlargement of fields is expensive. On the other hand, such fences, properly built with foundations that will not heave with frost action, are the most enduring of all types; moreover, they are attractive and are fireproof, often preventing a blaze spreading from field to field.

The extent to which stone is used for fencing is quite variable in different parts of the country. Throughout the Great Plains region of the Middle West very little stone occurs, and the Rocky Mountain and Far West States have few stone fences. In the New England and other Eastern States, however, granite and limestone boulders abound and have been widely used for this purpose. Throughout Connecticut, Rhode Island, and other Northeastern States there are miles and miles of fences made of the abundant granites and other igneous rocks. In northern Virginia many roads and fields are neatly fenced for long stretches with limestone boulders.

Data for determining the mileage of stone fences in the United States are meager. In so far as the writer has ascertained statistics cover only

the North Central States and certain selected parts of New York. The first of these areas comprises States where very little stone is found on farms, and consequently few such fences are built. According to a report[39] of the United States Department of Agriculture only about 0.17 per cent of the fences were of stone in the following 11 States: South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio. In this group Wisconsin stands highest, with 0.8 per cent. A second recorded study by Myers[40] covered 53 farms in New York averaging 173.4 acres each. The average length of stone fence per farm was 122.5 rods, or 8.1 per cent of the total fencing. In certain sections the percentage ran as high as 36.

If it is assumed that the figure 8.1 per cent, obtained by Cornell University for parts of New York, typifies the more rugged and older settled parts of the East, which occupy about one sixth of the area of the United States, and that the figure, 0.17 per cent, obtained by the United States Department of Agriculture for the North Central States, is a fair average for the rest of the country, a basis has been established for estimating the total extent of stone fences. Figures thus obtained may be far from correct, but they at least supply an estimate on which to hinge comments until better figures are obtainable.

According to census figures, some years ago there were 5,371,000,000 rods of fence in the United States. On the basis given above the approximate length of stone fences would be 78,620,000 rods or about 246,000 miles.

To determine the cubic contents of this volume of fencing a certain amount of guesswork again is required, for fences are not of uniform size; some built long ago are massive, while others, especially those built more recently are of much smaller proportions. Many limestone fences in Virginia are about 2 feet wide at the bottom, 1 foot wide at the top, and 4½ to 5 feet high. If average dimensions are assumed to be 2½ feet wide at the bottom, 1½ feet at top, and 5 feet high, the total volume would reach the staggering figure of nearly 13,000,000,000 cubic feet. Practically all the fences are dry walls built without mortar. The stones are laid carefully and packed so closely that the air spaces between them probably do not occupy more than one fourth of the entire volume. Assuming that three fourths of the volume is solid stone weighing about 160 pounds to the cubic foot the weight of stone used in fences approaches 780,000,000 tons, which is equivalent to about 280 times the production of dimension stone in the United States in 1931. The figures

[39] Humphrey, H. N., Cost of Fencing Farms in the North Central States. U. S. Dept. of Agriculture Bull. 321, 1909.

[40] Myers, W. I., An Economic Study of Farm Layout. Cornell Univ. Agric. Exp. Sta. Memoir 34, 1920.

given above may, of course, be very much in error, but at least they show a use of stone of very great magnitude.

This lowly application that finds no place in statistics and little mention in song or story fills in toto an important place in rural life. But what of the future? As stone fences gradually deteriorate through action of the elements, the high cost of labor for repairs or rebuilding leads to replacement of many of them with wire fences. The widening of highways and enlargement of fields may also demand their removal. The

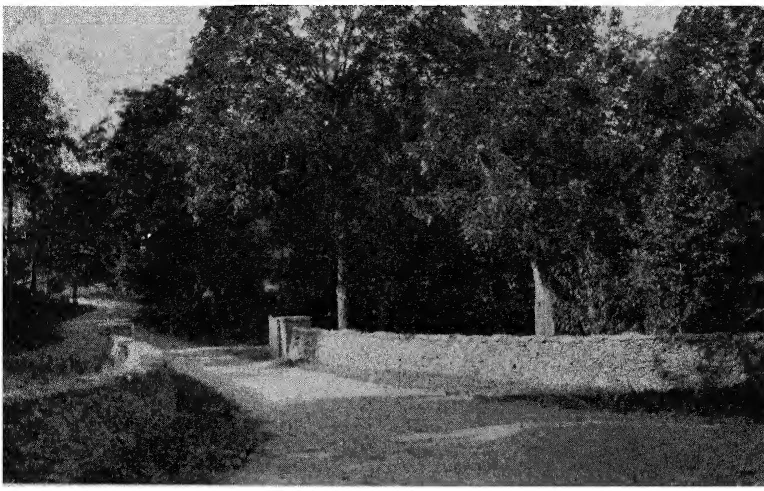

FIG. 59.—Graceful limestone fences in Virginia. (*Photo by the author.*)

material from some of them has been used for building purposes, or crushed for hard-road construction. Diminishing use is in prospect, but any movement toward wholesale destruction is to be regretted, for nothing is more enduring than the rocks from which this old world is made. Not only are stone fences substantial and long lived, but they are picturesque and lend an attractiveness to rural landscapes that would be sadly missed.

It is evident that the dignity, stability, and ruggedness of stone fences are fully appreciated in some localities. During active repaving and road widening in northern Virginia in 1930 and 1931, numerous stone fences were moved back and rebuilt in attractive forms that enhance the beauty of an already charming landscape. Pillored gateways and graceful curves, as illustrated in figure 59, feature both new and old fences. Such structures add the charm of artistry to the utility of substantial and enduring stone.

USE OF BOULDERS IN BUILDINGS

As stated previously, boulders were used by the early settlers long before the days of quarrying. Although modern methods have made it

possible to shape bed rock into building units quickly and at moderate cost, the use of boulders has by no means been abandoned; they are still popular and are widely used. Perhaps their most prominent use is in rustic fireplaces and exterior chimneys, the latter constituting prominent features of many beautifully designed residences. They are also used extensively for basements, lower courses, and porch walls. Entire exterior house walls of boulders are by no means uncommon; in fact, the present demand for ruggedness and variety in architecture has led to increasing use. An unusual use is shown in figure 60.

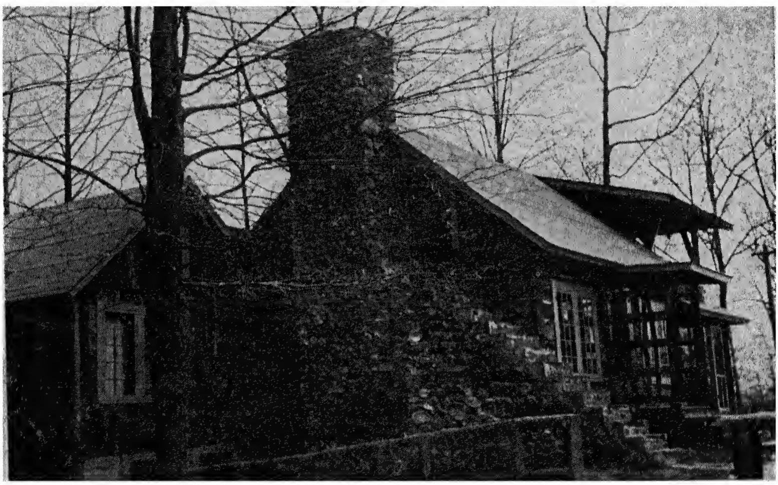

FIG. 60.—A unique type of boulder construction combining chimney with stairway. (*Photo by H. Herbert Hughes.*)

As mentioned heretofore, the greatest variation in materials is in glaciated country. In such regions boulder houses may have in the same wall granites, gneisses, syenites, trap rocks, limestones, sandstones, and mica schists interspersed occasionally with beautiful red jasper conglomerates.

The use of boulders is not confined to modest dwelling houses. Many mansions costing thousands of dollars, mountain resorts, hotels, and public buildings are built largely of them. Farmers may be paid by the wagon load for hauling rocks from their farms to build such structures. Although the work of construction is slow and expensive many buildings of this type are of beautiful rustic design; they will endure for many years, and their maintenance cost is low.

CHAPTER XIII

FOREIGN BUILDING AND ORNAMENTAL STONES[41]

SCOPE OF DISCUSSION

Many foreign countries are rich in structural and ornamental materials of mineral origin. In the Old World structural stones were used far back in prehistoric ages, and the acid test of time has proved that many are remarkably enduring. Multitudes of beautiful, serviceable American stones are no doubt just as capable of resisting the storms of centuries, but our New World civilization is as yet far too young to prove their qualities. In European countries magnificent cathedrals and other public buildings erected centuries ago are centers of interest for travelers from all nations. It is fitting, therefore, that some attention be given to the sources of supply of materials which people of foreign lands have found to be essential for the noblest and most substantial types of architecture.

The primary purpose of this book is to cover adequately the stone industries of the United States, for space would not permit a treatise covering in detail these industries throughout the world. Nevertheless, many foreign stones are now, or have been, used extensively in America, and it is therefore desirable to give some attention to those that are used in conjunction with, or as substitutes for, stone of domestic origin. As brevity is necessary, attention will be given chiefly to stones from other lands that find prominent use in the United States.

IMPORTS OF STONE

To indicate the extent to which foreign stones are used in this country, a table of imports compiled by the United States Bureau of Mines is shown on page 302. It comprises a table covering stone, to which has been added the value of imported slate.

The future consumption of foreign stone in America is hard to predict. Demands during the depression years were subnormal and, coupled with depressed markets, imports have been and will continue to be influenced by the tariff revision of 1930 and subsequent revisions.

[41] Acknowledgment is hereby made of helpful information obtained from certain unpublished manuscripts on foreign building stones compiled some years ago by T. C. Hopkins for the U. S. Geol. Survey.

Stone Imported for Consumption in the United States, 1929–1930 and 1936–1937, by Kinds

Kind	1929		1930		1936		1937	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Marble, breccia, and onyx:								
In blocks, rough, etc., cubic feet	667,900	$1,591,070	717,436	$1,578,856	60,784	$256,922	75,302	$297,501
Sawed, cubic feet	10,859	24,799	797	2,983	172	712	165	488
Slabs or paving tiles, superficial feet..........	649,899	253,267	591,616	254,179	150,364	58,979	214,588	67,789
All other manufactures	....	566,010	....	329,279	....	43,879	....	69,403
Mosaic cubes of marble or onyx, pounds	....	1,908	....	12,157	5,609	140	9,362	180
Total	....	$2,437,054	....	$2,177,454	....	$360,632	. ...	$435,361
Granite:								
Dressed, cubic feet..........	....	$ 292,644	....	$ 266,318	16,233	$ 67,293	36,853	$178,607
Rough, cubic feet	216,022	378,943	138,831	202,037	43,089	63,627	43,871	67,212
Total...........	....	$ 671,587	....	$ 428,355	59,322	$130,920	80,724	$245,819
Quartzite, short tons............	*	*	102,032†	$ 174,334†	50,704	$ 91,120	139,533	$249,003
Travertine, cubic feet............	*	*	74,163†	64,997†	48,917	67,185	13,404	18,677
Stone (other):								
Dressed.........	....	$ 62,674	....	$ 23,396	....	$ 5,471	....	$ 6,310
Rough (monumental or building), cubic feet..........	240,399	184,620	214,424	203,417	2,229	3,688	2,547	6,617
Rough (other), cubic feet.....	....	233,324	....	73,908	3,939	7,050	6,287	19,639
Total	....	$ 480,618	... .	$ 300,721	....	$ 16,209	... .	$ 32,566
Slate............	....	$ 95,073	....	$ 48,065	....	$ 4,851	....	$ 4,824
Grand total.....	....	$3,684,332	....	$3,193,926	.... ..	$670,917	....	$986,250

* Not separately classified.

† Figures cover June 18 to December 31: not separately classified prior to change in tariff.

FOREIGN LIMESTONES

Canada.—The Tyndall limestone of Ordovician age, occurring about 30 miles northwest of Winnipeg, Manitoba, generally is regarded as the best building limestone in western Canada. The main productive ridge is about ½ mile wide and 1 mile long, although less easily available rock occurs over a much wider area. Two main types of stone are obtained—

an upper buff-mottled stone in beds 12 to 13 feet thick in all, and a lower blue-mottled stone 5 to 6 feet thick. Both kinds extended below the floor of the quarry at the stage of progress covered by Park's original description (see bibliography), and the total thickness of the formation was about 130 feet. The rock has a characteristic mottled appearance due to evenly distributed dark patches. Blocks are sawed, cut, and carved in large, well-equipped finishing mills, either at the quarries or in Winnipeg. Some waste material is burned into lime. The product is used widely for public buildings in Winnipeg and other midwestern cities.

Limestones are plentiful in Ontario, and numerous quarries have been opened in many localities. Most of them, however, are small and supply stone only for local use. Dark, heavily bedded limestones of the Black River formation have been used so widely in Kingston that it has been called the Limestone City. Other noteworthy occurrences are the Trenton, which is used to some extent in Ottawa; the Niagara limestone at Hamilton; and the Onondaga near St. Marys. The largest building limestone quarry in Ontario is at Queenston near Niagara Falls. While it has been worked for many years, activities have been enlarged greatly under new ownership since 1925. Rock of high quality occurs in flat-lying beds about 15 feet thick all told, with a moderate overburden. The stone is a pleasing silver gray that mellows with time. It has low absorptive properties and is highly resistant to weathering. The quarry product is sold as rough blocks or slabs for fabrication in independent mills. It is used in constructing many large buildings in Hamilton, Toronto, and other Canadian cities.

Numerous buildings in Montreal are made of limestone quarried in or near the city. The stone belongs to the Chazy and Trenton formations and is of three main types. The first, a grayish, medium-grained, semi-crystalline limestone is of the highest grade and is suitable for cut stone. The second, a hard, dark, fine-grained variety, and the third, an inter-banding of the first and second, are used mainly for rock-faced work. Trenton limestones have been quarried extensively in Portneuf County, Quebec, and used for building purposes in Quebec city and in Montreal.

Cuba.—Buff and blue oolitic limestone is quarried in the suburbs of Havana. It is somewhat like Indiana limestone but is finer-grained and softer. It may be cut readily with an ax or hand saw but hardens upon exposure. As the deposit is conveniently situated and easily worked the stone is used quite extensively for building houses in Havana.

Bermuda.—Bermuda limestone is a porous aggregation of shell and coral fragments, ranging from a chalky, white, fine-grained, soft type to a darker, coarser, and harder form. It is worked so easily that blocks are cut out with long-handled chisels and subdivided to desired sizes and shapes with hand saws. Many houses are built of the softer types; even the roofs consist of thin slabs. When whitewashed this variety is

durable enough for a mild, moderate climate like that of Bermuda. The harder rock has been used for fortifications and other Government works on the islands.

France.—The Caen stone, a Jurassic oolitic variety quarried near Caen, Falaise, and Bayeux in Normandy, is one of the best known limestones of France. It is a soft, fine-grained, light-colored rock admirably adapted for carved work. While not suitable for outdoor use in a climate like that of the United States it has been popular for many centuries as an interior decorative stone, particularly in Gothic architecture. It was

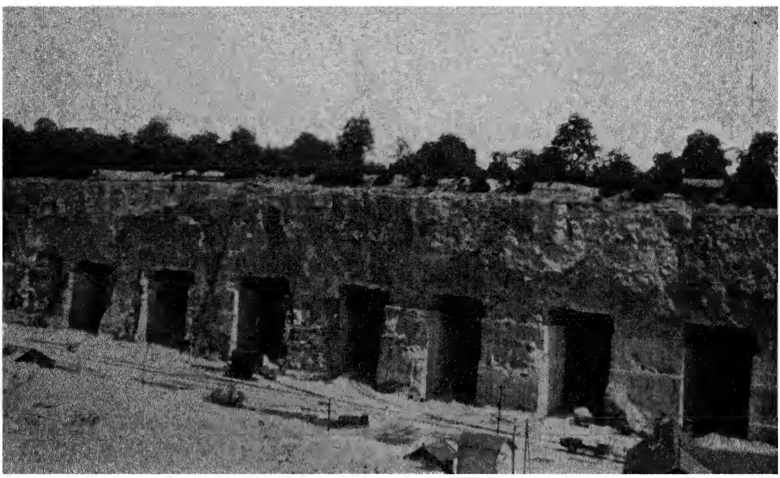

FIG. 61.—Underground limestone mines, Commercy, France. (*Courtesy of J. B. Newsom.*)

shipped to England in large quantities shortly after the Norman conquest and employed in such notable structures as the Cathedral of Canterbury and Westminster Abbey. The workable beds have a maximum thickness of 20 to 25 feet and cover a wide area. Most of the workings are underground, though some stone is taken from open quarries. It is shipped by water to various European ports and to America.

Jurassic oolitic limestones are quarried also in the Department of Meuse on the east side of the Paris Basin. Highly fossiliferous stone, consisting chiefly of crinoid fragments, is obtained from open-pit quarries at Euville and Lerouville and from underground workings at Commercy. The latter are shown in figure 61. This has been used for fortifications, canals, and many notable buildings in Paris. "Comblanchien" is a well-known Jurassic type. As shown in figure 62, canals are of great assistance in transportation.

Large quarries of similar stone have long been worked near Auxerre in the Department of Yonne southeast of Paris. It is reported that 43

quarries were operated in 1889. Large saw mills were employed to shape blocks for the construction of canals and as building stone used in France, England, Belgium, and the United States.

Jurassic oolites and Lower Cretaceous limestones are quarried extensively near Grenoble in Isere. "Eschaillon White," "Eschaillon Rose," and "Eschaillon Yellow," some varieties of which are classed as marbles, have been used for architectural purposes in various French cities. The rose variety occurs in a bed 4.5 meters thick, while the white is 16.5 meters thick.

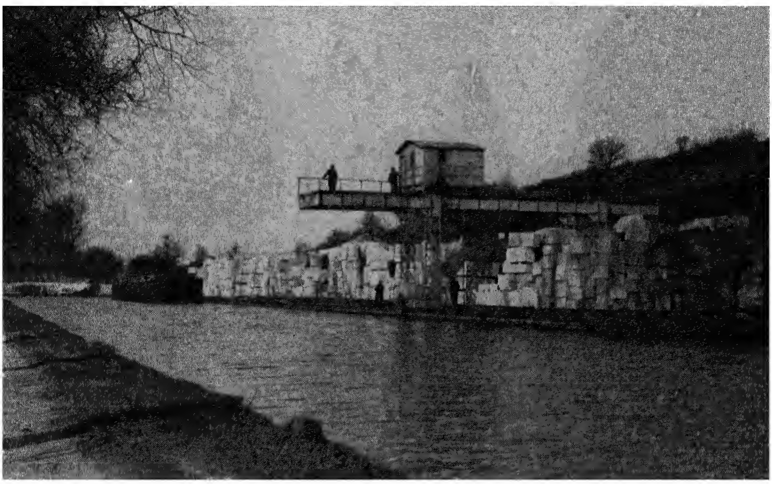

FIG. 62.—A canal in France used for transporting stone. (*Courtesy of J. B. Newsom.*)

Tertiary limestones of the Paris Basin have been worked in extensive underground galleries since the early Christian era. The most important building-stone stratum, known as the *calcaire grossier*, or big limestone bed, is a fossiliferous yellowish to grayish white stone coarse to fine in texture. In mining the high-grade rock in beds only 16 to 20 inches thick several feet of waste rock are removed to obtain working space in the galleries. The architectural beauty of Paris is due in no small part to the patience and industry of miners who drove tunnels many miles beneath parts of the city to obtain a building material of such superior quality and attractiveness that it has been preferred to most other structural products.

The Tertiary limestones of southern France have been used widely for building. This great belt extends eastward from the Pyrenees through the Alps and Apennines into Greece and through the Carpathians and Balkans into Asia Minor, and continues through central Asia to China and Japan. It occurs south of the Mediterranean Sea in Egypt and in the Barbary States. An important bed, known as the Num-

mulitic limestone, has been quarried in most of the countries through which it passes and provided stone for such famous structures as the Great Pyramid of Cheops and many buildings in the Holy Land.

Belgium.—One of the best building limestones of Belgium is a bluish gray to black fossiliferous rock of Devonian age. Some of it is composed almost entirely of crinoid fragments, assembled in such a way as to present a granitic texture, on which account it is called *petit granit.* It works easily, has high crushing strength, and resists weathering remarkably well. Large quarries are worked at Ecaussinnes, Soignies, Arquennes, and Feluy in Hainaut, at Spontin in Namur, and Sprimont in Liege. Other quarry centers are Maffles, Anthisnes, Comblain au Pont, Denee and Les Awins. High quality stone has been quarried at Soignies since 1740 and used extensively along the canals of Holland. It is also exported to Germany, France, England, and the United States. Some is designated commercially as marble. The lower beds are quarried with wire saws; the standards are set in core-drill holes 3 feet in diameter and about 13 feet deep.

Italy.—Travertine is usually classed as limestone. The most famous deposits in the world occur near Tivoli about 16 miles east of Rome. Del Barco near the famous baths of Acque Albule at Bagni, a railway station between Rome and Tivoli, is one of the oldest quarries. It furnished stone during the days of the Roman Empire. According to information obtained from Frank L. Hess of the United States Bureau of Mines, who visited the district in 1929, the quarry was about 1,000 feet long and 22 feet deep. The overburden is unconsolidated material 10 to 15 feet thick, much of which consists of artificial accumulations. Rock at the western end of the quarry is variegated gray and white, stained with iron oxide in places. In recent years this type has become more popular, whereas formerly the only kind used was the more regularly colored rock at the eastern end of the quarry.

For several centuries blocks were separated by a slow process of cutting hand-picked channels on four sides and then wedging up at the floor. The stone is now cut with wire saws into blocks about 10 meters long, 1 meter thick, and 2 to 3 meters high. The length is governed by the spacing of major joints, some of which have been widened enough by solution to afford room for setting up standards for the guide wheels. The rate of sawing is about 4.5 square feet an hour. When long masses are cut to the bottom they are wedged free at the floor, and broken across in several places. Each block is turned down by fastening a wire cable to it and pulling it over by means of a capstan turned with oxen. Irregular blocks are trimmed to shape with wire saws. Large rectangular masses are cut into thin slabs with gang saws using sand as abrasive. It was reported that blocks could be put on cars at Bagni for about 350 lire a cubic meter and on board trans-Atlantic ships for about 400 lire. In

1929, the time of this estimate, 19 lire were equivalent to about one dollar. The above costs. therefore, were respectively about 56 and 71 cents a cubic foot.

The travertine area is extensive, and several quarries other than that described are worked. St. Peter's, one of the greatest churches in the world, and the famous Colosseum, the largest theater, begun by Vespasian in A.D. 75 and dedicated by Titus in A.D. 80, were built chiefly of travertine from the Tivoli quarries. During the fifteenth and sixteenth centuries the Colosseum was used as a quarry where stone was procured for many churches and palaces in Italy, notably the Piazza di San Marco in Venice and the historic Palazzo Farnese in Rome. Demolition was finally stopped, and the structure was partly restored. During recent years large quantities of Italian travertine have been imported for interior decorative and structural uses in America. The Pisani quarry, not far from the Del Barco, supplied travertine for the Pennsylvania Railway Station in New York, which attracted much attention and popularized the use of Italian travertine in America. As shown in the the table of stone imports on page 302, travertine was not separated from other stone imports before 1930. It has been stated in hearings before the United States Tariff Commission that imports for some years amounted annually to about 100,000 cubic feet, and that the selling price in New York was about $2.25 a cubic foot.

A closely related calcareous tufa is obtained near Naples. Blocks are quarried and prepared for market entirely by hand methods.

England.—The most notable building limestone of England is a Jurassic oolite occupying the same prominent position in the building trade of that country that the Caen stone holds in France and Indiana limestone in the United States. The formation is divided into four bands: (1) The upper (Portland), (2) the middle (Oxford), (3) the lower (Bath), and (4) the Inferior Oolite. The first and third are most important, although the fourth has supplied much good building stone.

The Bath stone of the lower beds quarried in Wiltshire is the most famous and most widely used. About 2,000,000 cubic feet are quarried annually for domestic use and export. The rock is softer, finer-grained, and more uniform than the Portland stone described later and is admirably suited for the delicate carvings of Gothic architecture. It is a pure limestone containing more than 97 per cent calcium carbonate. The most important workings are in the Somerset Hills near Bath, where beds are 12 to 25 feet thick and very extensive. Most of them are worked underground and reached by inclined tunnels. The first operation is to pick a horizontal space several inches high at the roof. Vertical cuts are made with hand saws having one handle. After blocks are broken loose at the base they are drawn out with powerful cranes, squared with ax or saw, loaded on low tram cars, and hauled through

tunnels to the surface with horses or cable hoists. Excavations are very extensive; it is claimed that some larger companies have no less than 60 miles of tunnels. Squared blocks weigh 6 to 10 tons each. The stone is hauled by railway cars to docks at Bristol and Avonmouth for shipment by water. Like Indiana limestone, the Bath stone will suffer from frost action if not first seasoned. Work is continued underground throughout the year, but in winter blocks are stored in headings that have been worked out. They are brought to the surface about April and piled in storage yards or shipped to customers. Before the World War Bath stone was sawed into slabs by hand, but the requirements of that period necessitated installing machines to conserve labor. Gang saws are used for subdividing into slabs and circular saws for crosscuts. Since the war large quantities of Bath stone have been cut to standard sizes, 6½ by 4½ inches, and in lengths ranging from 9 inches to 2 feet 3 inches. Such sizes are laid by bricklayers and sold in competition with brick. Houses made of them are much less expensive than cut-stone structures. Carefully selected Bath stone is durable in the British climate. For centuries it has been used for most of the beautiful ecclesiastical structures of western England, including the Abbey Church of Bath, Glastonbury Abbey Church built in the eleventh century, and Wells Cathedral begun in the twelfth century, all of which are still well-preserved. Bath stone sometimes is imported into the United States in considerable quantities and sold through New York dealers. It has been used for interiors and exteriors of many large buildings.

Portland stone ranks next to Bath stone in commercial importance. The name is derived from Portland Island on the Dorset coast, where the chief quarries are situated. It is harder and less uniform in texture than Bath stone and better adapted for the more massive Italian architecture. It was a favorite material employed by Sir Christopher Wren and other architects for rebuilding London after the great fire of 1666. Sir Christopher controlled the Portland quarries during the construction of St. Paul's Cathedral, begun in 1675. The harder and more durable stone comprises the Whit bed; and the Best, or Base bed contains material suitable for fine carving and interior work. An overlying bed, known as the "Purbeck-Portland" stone, has been mined underground for many centuries. A section of the Whit bed 1½ to 4 feet thick, known as "Perricot" stone, is crystalline and unusually fossiliferous. It is particularly adaptable for the manufacture of highly polished interior-decorative slabs.

The first hydraulic cement manufactured in England, when mixed with water and allowed to set, formed a massive rocklike substance closely resembling Portland stone. For this reason it was called "Portland cement," a name which has been retained in England and in America.

A ferruginous limestone known as "Horton stone" is quarried for building purposes at Edgehill, Warwickshire. Another important center is about 12 miles from Salisbury, where the Chilmark siliceous limestone is still being mined for building purposes, chiefly in Winchester. This stone was used for the construction of Salisbury Cathedral, erected about 700 years ago.

A white limestone in beds totaling 11½ feet in thickness has been worked underground for centuries at Beer on the south coast of Devonshire. "Beer" stone was used in Exeter Cathedral and many other notable structures but during recent years has been worked on only a small scale.

A 4-foot bed of cream oolitic limestone is quarried for building at Ketton, southeastern Rutland County. It was used in the construction of the Cathedral of Ely, the Cathedral of Peterborough, and many other ancient and modern buildings. The quarries first were opened under Royal charter in 1301. Similar oolitic limestone quarried near Clipsham, northern Rutland County, has been used quite extensively for restoring the Houses of Parliament and various cathedrals. A creamy oolitic limestone has been quarried for many centuries at Weldon, Northampton, a few miles south of the Rutland County quarries. Kirby Hall, bearing the date 1593, was built of this stone.

FOREIGN SANDSTONES

Canada.—Potsdam-Beekmantown sandstones of Cambrian age occur in southern Ontario and have attained some importance in the Ottawa district. White, brown, and yellow stones have been used for such notable structures as the Parliament Buildings, the Museum, and the Archives Building. Medina sandstone occurs in Ontario in a bed averaging about 12 feet in thickness, which outcrops along the Niagara escarpment from near Niagara Falls through Hamilton, Credit Forks, and Orangeville to Shelburne. It appears in three chief colors, brown, gray, and mottled. Brown stone from the Credit Forks district is of the highest quality and was used to construct the Parliament Buildings and many other edifices in Toronto. Virtual cessation of quarrying is due largely to difficulty of working steep outcrops that have a heavy overburden of Niagara limestone.

The Permo-Carboniferous and the Millstone Grit of Middle Carboniferous age have supplied olive green, gray, red, and brown sandstones for local use in many parts of the Maritime Provinces. The Paskapoo formation of Eocene age furnishes the best building stone in the Prairie Provinces, except for the Tyndall limestone. It is soft, easily worked, and occurs in a variety of colors which have made it an attractive stone for use in Edmonton, Calgary, and other cities. It is quarried principally

near Calgary and at various points north and south along the line of the Canadian Pacific Railway.

Other Canadian sandstones worthy of mention are the "Sillery," which was used extensively in construction of the citadel of Quebec, and the blue to buff "Cowichan," quarried on Gabriola and Saturna Islands, British Columbia, for buildings in Victoria and Vancouver.

France.—Sandstones are widespread in France, having been worked in at least 36 Departments, but they are employed mainly for local use. The more important quarries are in the Triassic and Tertiary formations; for many centuries these have furnished stone for constructing bridges, churches, canals, fortifications, and pavements. As means of transportation have improved many less desirable quarries have been abandoned in favor of better stone obtainable at more distant points. The industry has little international importance.

British Isles.—The "Old Red" sandstone of Devonian age is quarried extensively in England and Scotland. A deposit in England bordering South Wales supplied stone for such notable structures as Tintern Abbey, built in the thirteenth century and still well-preserved. In Scotland the largest areas extend from Moray Firth to the Orkney Islands in the north and from Dumbarton northeast to Stonehaven in the south-central region. The stone has been used locally and also shipped in large quantities to London and other English cities for building stone, trim, flagging, and curbing. The famous Caithness flagstone of northern Scotland has provided much of this material.

Lower Carboniferous sandstones occur in northern England and southern Scotland. Quarries in Northumberland were worked by the Romans to build the piers of a bridge over the North Tyne about A. D. 120; the piers are still in good condition. The same formation, quarried extensively on both sides of the Clyde and the Forth, furnishes some of Scotland's finest building stone. The architecture of Edinburgh and Glasgow has been influenced by sandstone in much the same way as that of Aberdeen has been dominated by granite.

The Millstone Grit of Carboniferous age, occurring in Derby, Lancashire, Newcastle, and Northumberland, provides a coarse-grained massive stone suitable for heavy foundations, piers, and docks and a finer-grained variety for superstructures and trim. Coal Measures sandstone lying above the Millstone Grit has been used widely in and about Bradford, York; Nelson, East Lancashire; Durham; and Northumberland. Permian sandstones in Devon, Shropshire, and Cumberland furnish some good building stone.

The Triassic, known as "New Red" sandstones, are distributed widely over central and northwestern England. Stone quarried on the cliffs at St. Bees Head near Whitehaven, northwestern England, was used for Washington's home at Mount Vernon. Red Triassic sandstones have

been quarried extensively in Cheshire. The famous Warwick Castle was built of this stone, and similar sandstone is found in many buildings in Liverpool, Old Chester, and other cities of that region.

New Red sandstone of high quality, occurring in Dumfries and Ayr, southern Scotland, has been used widely in the British Isles and exported to the United States, Canada, and other countries. Much of that shipped to America is bright red stone from near Thornhill and Annan, Dumfries. It has been used in the interior of the State Capitol in Albany, the American Fire Insurance Building in Baltimore, and the Telephone and Telegraph Building in Boston.

Africa.—Sandstones abound in the Union of South Africa and are quarried for local use in many places. Among the most widely used are the Table Mountain sandstone at Nieuwoudtville and Cape Town, Cape of Good Hope, and the Karroo sandstone at Steenpan, Flatpan, and Ladybrand, Orange Free State. Coal Measures sandstone is quarried at many points in the Transvaal.

FOREIGN GRANITES

Canada.—Probably no country in the world exceeds Canada in extent of granitic rocks. The great Archean shield, consisting chiefly of granite and gneiss, extends from the Great Lakes northeast to the wilds of Labrador, northwest to the Yukon, and, except for the interruption of a small sedimentary area near Hudson Bay, north for an unknown distance into the Arctic regions. All but an infinitesimal part is either unsuited for dimension stone or is beyond economic reach of markets. Commercial development has been confined to easily accessible parts or to outlying areas near centers of population.

Ontario.—An attractive red granite has been quarried near Kingston, Ontario, but its close jointing causes much waste which makes it difficult to compete with stone imported from Aberdeen, Scotland. Granites abound in the Thousand Islands district, but inability to obtain large blocks without excessive waste discourages production, except for paving blocks. Stone for rough construction is quarried near Parry Sound.

Maritime Provinces.—The most important granite area in the Maritime Provinces is near the town of St. George, Charlotte County, New Brunswick. The best stone from this district is a coarse-grained red granite suitable for monuments and decorative building. Pink and light gray varieties are also obtained. Numerous small quarries have supplied blocks to finishing mills in St. George. West of St. John River opposite Spoon Island pink and gray monumental and building granites have been quarried for many years. A gray building variety is obtained from boulders near McAdam Junction, New Brunswick. Near West Nictaux, Annapolis County, Nova Scotia, a fine-grained gray monu-

mental and building granite is quarried, but excessive jointing is a serious obstacle to extensive development. A coarse-grained gray variety, used in many large buildings in Halifax and Sydney, has been quarried near the eastern edge of a great granite mass stretching westward from the harbor of Halifax, Nova Scotia. Black granite (diabase) is available in several areas but has been little worked; activity is in prospect near Loch Katrine. An undeveloped reddish and variegated felsite-breccia commercially related to granite occurs on Scatari Island, Cape Breton County, Nova Scotia. It is attractive, takes a good polish, and is available in pieces large enough for clock cases, statuettes, fireplace tile, and novelties.

Quebec.—Coarse-grained granites of pre-Cambrian age are quarried in Quebec at Riviere á Pierre, Portneuf County; Roberval, Lake St. John County; Brownsburg, Argenteuil County; and in Ottawa County. They are used principally as building stone and for paving blocks. The most important producing area for building granite in Canada is in Stanstead County near the United States border. The rock is a medium-grained light gray intrusive granite of later age than surrounding sediments. It has been employed for many buildings in Montreal, Toronto, Ottawa, and other eastern cities, and some has been shipped to the Prairie Provinces. Well-equipped mills are maintained for sawing, dressing, polishing, and cutting into columns. At Mount Johnson 6 miles east of St. John fine-, medium-, and coarse-grained black granites (diabases or diorites) are obtained. One variety is marketed as monumental stone under the trade name "Canadian Quincy."

Western Provinces.—In the Prairie Provinces the only granite now of any importance is a dark, variable colored, medium- to coarse-grained rock of pre-Cambrian age occurring east of Lake Winnipeg, Manitoba, and used to a limited extent for rough building. British Columbia has an abundance and variety of granitic rocks. Gray to pale pink granite of pre-Cambrian age has been quarried in a small way near Lake Okanagan for buildings and monuments. The great Coast Range, extending 850 miles along the coast, consists of a variety of igneous rocks ranging in composition from true granites through granodiorites to more basic types, such as gabbro. They furnish the most important building and monumental stones of the Province. The best-known commercial stone is a gray granodiorite of the Jervis Inlet area quarried on Nelson, Hardy, Fox, and Granite Islands and used for many important buildnigs in Vancouver and Victoria. An extensive occurrence of gray granodiorite near Nelson has been worked for building stone in several localities. An attractive gray andesite suitable for building stone has been obtained on Haddington Island.

Scotland.—"Scotch granite" is a familiar term among stone dealers and users because granites from Aberdeen and Peterhead were the first

to enter international trade extensively. Wide use throughout Great Britain led to their introduction into the United States by early settlers of British extraction; thus, they became firmly established as standard memorial stones in America. Aberdeen granite is gray to light blue and of fine to medium texture. Peterhead granite, quarried north of Aberdeen, is prevailingly red and polishes well. The Aberdeen industry began about 300 years ago, and many quarries worked downward 200 to 300 feet are so deep and narrow that they have been abandoned. Compressed air was first used for drilling in 1899. The stone has been used widely for monuments, buildings, locks and harbors, and paving. The paving industry was at one time very important but has declined greatly with the substitution of other types of street and highway construction. Aberdeen, known as the Granite City, is built largely of stone from near-by quarries. It has become so important as a marketing center that granites from other parts of Scotland and from the Scandinavian countries are marketed through it and are sometimes sold as Aberdeen granites.

Curbing, building stone, and monumental granite are produced at Creetown, Kirkcudbright County. The quarries have produced steadily for a hundred years.

Ireland.—A great variety of granites occurs in Ireland; they have been worked in many places, particularly in Dublin, Wicklow, and Wexford Counties. Gray and red granites that take a good polish are abundant, but production has been spasmodic, and no export trade of importance has developed. They have been used widely for local building and paving for many centuries.

England.—The most important commercial granites of England occur in Cornwall and Devon. Granite was used as early as 1756 for the exterior of Eddystone Lighthouse. The Devon rock is gray, somewhat porphyritic, and better adapted for heavy masonry than for decorative purposes. It was used in London Bridge and many other massive structures. Silver-gray granite is plentiful in Cornwall. It is quarried chiefly at Boslymon and Carne for curbing and heavy masonry. The Cornish granite industry normally employs about 2,600 men. At Shap, Westmoreland County, a very attractive porphyritic granite with flesh-colored orthoclase crystals is produced for decorative and building purposes, and some is shipped to the United States. Granites from Scotland and elsewhere are finished in well-equipped shops in this district. At Mount Sorrel, Leicester, a gray to light reddish brown variety (granodiorite) is quarried for monumental work. Diorite quarried at Nuneaton, Warwickshire, is manufactured into curbing, paving blocks (setts), and other products.

Norway.—Granite has long been used in Norway, but only since 1876 has production become important through development of a large export

trade. A small area in the southern part of the country near the Swedish frontier produces 70 to 80 per cent of the total output. A very beautiful gray syenite quarried at Laurvik has no counterpart in America. It contains tabular, iridescent crystals of plagioclase (Laurvikite) which present a striking display of colors on polished surfaces. It is marketed as "Norwegian Pearl Gray" for interior and exterior decoration. A notable example is to be found in the exterior lower courses of the Chrysler Building in New York. Another Norwegian syenite (Nordmarkite), composed principally of red microperthite, occupies a large area north of Christiania and is used for house construction in and about that city. Many quarries are near the seashore, where overburden has been removed by glacial action. The advantages of availability and transportation by water enable Norwegian producers to compete successfully in foreign markets of Europe and America.

Sweden.—Prior to 1350, 94 churches on the island of Gotland were built of granite quarried on the island. Granite was first used in quantity for building purposes on the mainland of Sweden in the sixteenth century. About the middle of the seventeenth century brick became a popular building material, and stone quarries were neglected for nearly 100 years, but the granite industry was reestablished during the canal-construction period of the eighteenth century.

Red and other ornamental granites, such as "Swedish Rose," are popular for polished monumental work at home and abroad. Building stone is also exported; a notable example of its use is in the Peace Palace at The Hague. While the entire coast of Sweden from Halland north to the Norwegian boundary is a continuous stretch of granitic rock, greatest development has been in the Goteborg district at the north where the rock is not only of excellent quality, but splitting properties are exceptionally well-developed. However, some important quarries are worked in the southern area in the Province of Halland.

An extensive deposit of gabbro, known to the trade as black granite, occurs in the Province of Jonkoping and is obtained chiefly from the Herrstad quarries. Large quantities are shipped in rough blocks to New York, where it is used extensively for building and manufactured into monuments which are sold principally in the New York area. Some rough blocks of Swedish black granite are manufactured into finished dies in Germany for export to the United States.

Paving blocks are an important part of the granite production of Sweden, as the export market was developed primarily for their disposal. The chief center of the industry is on the western coast in the Goteborg district where the rock has an excellent rift and run. Stones are subdivided very rapidly with splitting machines into small sizes, 3 to 4 inches in diameter, known as durex blocks; millions have been shipped to Argentina, North America, and Australia. The small blocks are pref-

erable for long-distance shipment as the weight of small stones required for a square yard of paving is little more than half that of ordinary paving blocks.

In the early development of the industry quarries were operated in a crude way by a large number of small landowners, but of late years they have been concentrated in the hands of a few large companies and have been modernized. Further stabilization was accomplished in 1929 when a working agreement in the nature of a cartel for control of production and marketing was reached among the principal Swedish and Norwegian quarry owners. This agreement covers production of paving stones and block granite.

From 90 to 95 per cent of the granite produced in Sweden is exported, about 50 per cent to Germany, 11 per cent to Czechoslovakia, 11 per cent to the United States, and 10 per cent to Great Britain.

Finland.—Finland is the most important source of foreign monumental granite for the United States. Granite shipped from Finland to the United States in 1931 was valued at about $120,000 and in 1937 about $187,000. These amounts were, respectively, about 50 and 76 per cent of the total value of granite imports. Red, gray, and black varieties are quarried in many places on the mainland and on islands in the Baltic Sea. The red type figures most prominently in foreign trade and comprises nearly all that exported to the United States. Much of it is shipped to Scotland, where it is manufactured and exported as "Red Balmoral," which sometimes passes as a Scottish granite. Other varieties include "Birkhall," a gray rock, "Russian Blue," and a black type obtained in smaller amounts. A granite of striking appearance, known as "Rapakivi," contains large, red, orthoclase crystals, some several inches in diameter. Paving and curbing production, though still important, has declined to some extent.

France.—Granite is distributed widely in France, the Paris Basin in the north-central part being the only large area without some granitic rock. It is now, or has been, quarried in more than 30 Departments. A great variety of attractive material is available, but very limited quantities are sold outside domestic markets. Gray granite from Vire in the Department of Calvados has been worked extensively for architectural uses, and some has been exported. Blue, blue-gray, rose, and red stones from coarse to fine in texture have been quarried at Finisterre in northwestern France for building piers, docks, bridges, lighthouses, and churches. Many granites, chiefly gray and bluish gray, have been obtained in the Department of Manche for military works, harbors, churches, and numerous other structures. Other igneous rocks such as tuffs and volcanic lavas, are used for local building.

Germany.—Large granite quarries and finishing plants are operated in Saxony and Bavaria, but production costs are high. The mills are

well-equipped with modern machinery, but the quarries are worked in crude fashion. As noted in previous pages, German stone mills obtain large supplies of rough blocks from foreign countries, particularly Sweden. Finished granite is exported from Dresden to the United States. Many basalt paving stones are manufactured in western Germany.

Italy.—The chief granites of Italy occur along the west bank of Lake Maggiore about 100 kilometers from Milan. Stone in various shades of red, capable of fine polish, is well-adapted for architectural uses and has been used in cathedrals and other buildings in Milan and Rome. Some has been exported to the United States and South America.

Switzerland.—The largest deposits of granite in Switzerland are found in the Cantons of Uri, Graubunden, and Tessin, greatest activity being centered in the last. Both building and monumental types are produced.

Egypt.—A coarse-grained, reddish hornblende granite, the ancient "Syene," occurs in extensive deposits along the Nile River near the town of Assouan. Thus originated the term "syenite," although in modern usage the Syene rock which contains much free quartz is not a true syenite. The Egyptian rock was quarried as early as 1300 B.C. and used for innumerable obelisks, columns, and statues. The obelisks have suffered very little deterioration in the mild, uniform climate of Egypt. An interesting account of the methods of quarrying, transportation, and erection of the obelisks has been published.[42]

South Africa.—Granites and related rocks of good quality are obtained in the Transvaal. The best-known varieties are the Bon-Accord norite, which is quarried about 8 miles north of Pretoria for building and monumental uses; the Leeuwfontein red syenite from near Hatherley; and the Pietersburg granite about 4 miles south of Pietersburg. The first and third varieties are now generally used.

FOREIGN MARBLES

Since ancient times marble, because of its attractiveness, workability, susceptibility to polish, and infinite variation in color and texture, has been a favorite material for sculpture and architecture. It commands a price high enough to justify shipment for long distances, therefore that of high quality can find markets in far-distant lands. Marbles are widely distributed throughout the world, many are types that have no counterparts outside their restricted localities, and numerous varieties are used in the United States; therefore important occurrences throughout the world are of interest to American producers and consumers.

The following table shows imports of marble from leading countries over a period of years. The figures compiled by the United States

[42] Engelbach, R., The Problem of the Obelisks: Bruce Humphries, Boston, 1931, 134 pp.

Department of Commerce show total imports from the country from which the material was last shipped, which is not necessarily the country of origin. For example, some of the stone imported from Belgium is French and Italian marble which has been manufactured into finished products in Belgian mills.

VALUE OF MARBLE IMPORTED INTO THE UNITED STATES, 1928–1937, BY COUNTRIES

	1928	1929	1930	1931	1932
Belgium	$ 169,692	$ 209,820	$ 410,295	$130,001	$ 58,331
France	283,553	420,405	370,920	142,214	34,566
Germany	131,620	129,891	133,691	71,535	25,648
Greece	73,840	47,178	71,989	11,543	2,957
Italy	1,593,096	1,418,519	1,023,435	454,119	245,612
Spain	26,807	47,072	47,654	21,275	7,491
United Kingdom	14,009	25,721	30,304	12,397	5,613
Canada	769	22,028	1,466	129	1,355
Mexico	97,969	78,166	69,844	12,069	

	1933	1934	1935	1936	1937
Belgium	$ 34,340	$ 20,047	$ 26,148	$ 54,062	$ 76,753
France	17,352	14,944	34,057	24,488	43,505
Germany	7,080	1,573	2,563	4,503	2,620
Greece	105	....	1,948	13	
Italy	132,211	70,752	95,011	150,217	142,636
Spain	22,047	3,868	4,391	1,290	
United Kingdom	6,472	2,410	9,966	5,245	4,076
Canada	5,101	2,418	98	648	1,469
Mexico	30	5,862	20,743	37,581	56,962
Argentina	54,306	58,990	94,378	72,091	75,840

Canada.—Marble has never been an important Canadian product, and the greater part of that produced is for local use only. Most of the few quarries operated are in the Province of Quebec.

Numerous occurrences have been noted in the crystalline area of southeastern Ontario, and though very little marble has been produced, reference may be made to some commercial types. "Arnprior," from Renfrew County, was used in the Parliament Buildings at Ottawa. "Cipollino Green" is a dark green, brecciated marble with occasional lighter spots and streaks. "Lanark Serpentine" is another type of green marble. "Rose Fantasia," from Hastings County, is a highly colored rock showing patches of bright red, salmon, and other colors embedded in a micaceous matrix. Crystalline limestones occur in various places in the Maritime Provinces, but no production of decorative stone is reported.

Attractive marbles are obtained near South Stukely in eastern Quebec, and rough blocks are shipped to a finishing mill at Montreal. The chief commercial types are "Jaune Royal," a light cream rock shot with greenish yellow veins and markings, and "Violette," which has a white background intersected with violet and green veins. High-quality marbles are produced also at Phillipsburg in the Missiquoi area, Quebec. "Rose Vert" has a green base with patches of mottled white and rose, some as large as 2 inches in diameter. "Vert Gris" has a grayish base traversed by fine, green lines. The quarry and mill at Phillipsburg are well-equipped. Attractive green serpentines occur at Orford Mountain, Quebec, but have not been developed.

Marbles of three general types occur in British Columbia—banded, reddish crinoidal, and pink and white dolomitic varieties. Commercial development is confined to the Kootenay quarries near Marblehead in rock of the first type, but production has been very small. Typical "Kootenay" is light gray with dark gray bands.

Cuba.—Several hundred tons of sawed marble a year are shipped from Nueva Gerona, Isle of Pines, to Cuba for use in Havana and other places on the island.

Italy.—Far back in the days of the Roman Empire the abundance and excellence of Carrara marble made Italy a world center of art and architecture as well as of marble production, and throughout succeeding years the name "Italy" has been associated with beautiful statues, monuments, and buildings wrought in that enduring stone. The country's supremacy in marble production was never challenged until recent years, when the United States became the chief producer and France assumed the lead in number of varieties. The most prominent Italian marbles reaching the American market are the white "Carrara," the yellow "Siena," and the colored varieties from Verona. Until recently about 80 per cent of all marble imports into the United States originated in Italy, but a much smaller proportion is now obtained from that source.

Carrara.—The Carrara marble district lies between Genoa and Pisa in the Carrara Mountains—a rugged range of the Apuan Alps reaching a height of 6,000 feet within a few miles of the sea. These mountains, which are regarded as of Triassic age, are in two parts, constituting a branching anticline. The initial thrust that caused intensive folding was from the southwest or Mediterranean side, where the slopes are about 45°. On the opposite or land side they average about 20°. The Carrara marble zone proper covers an area of about 64 square miles, and the chief quarries are on the steep seaward-facing slopes.

Marble classed as Carrara comes from four districts: Carrara proper furnishes about two thirds of the total production; Versilia, about 17 per cent; Massa, 10 per cent; and Garfagnana, about 6 per cent. Proportions, however, vary somewhat from year to year. The marbles may be

divided into three general groups—statuary, ordinary white, and colored. Roughly, about 10 per cent is of statuary grade; 75 per cent ordinary white; and 15 per cent colored and brecciated varieties.

Qualities that have made statuary marbles famous are fine grain, which lends itself admirably to the sculptor's chisel, pure white or creamy color, and translucence. They are divided into two classes, a pure white to cream, adapted for the best statuary work, and a bluish white decorative stone. The finest statuary marbles appear in comparatively small masses which occur to some extent in all the principal quarries. The principal statuary marble quarries are the Altissimo, Fondone and Gobie at Seravezza in the Versilia district. Except in the lower zones the masses occur within the ordinary white marble and gradually merge with it.

The ordinary white marbles are used principally for monuments. According to one classification they are subdivided into "Pavonazzo," cream with green and yellow markings; "Cipolin," with greenish markings similar to those found in Greek marbles of the same name; "Arabescato," with a network of veins; and "Calacata," a white marble with faint yellow streaks. Many special names are given to products of individual quarries. They are known as Sicilian marbles in England, because at one time they were shipped by way of Sicily.

The colored marbles are highly prized for decorative purposes. Some of the more important are "Bardiglio," from Seravezza, pale dove traversed with dark veins; "Breche de Seravezza," and other brecciated marbles; a greenish-white Cipolin marble known as "Pietra di Volegna," quarried near Pietrasanta; "Rosso Antico," which is deep red and "Viola Antico," which is purple.

The Carrara quarries first were worked by the Romans about 283 B.C. Marble suddenly became very popular in Rome about 27 B.C., for the Emperor Augustus boasted that he found Rome a city of brick and would leave a city of marble. The industry languished after the downfall of the Roman Empire but gradually assumed importance as marble became employed more widely throughout the civilized world. Periods of depression have been occasioned by various wars, but Carrara still maintains an important place among marble-producing districts. Several hundred quarries are operated, and normal annual production exceeds a half million metric tons.

Slow hand methods were used to separate quarry blocks before the invention of gunpowder. Thereafter explosives often were employed in sufficient quantity to start loosened blocks sliding down the steep mountain side. The rapid descent and powder blasts together caused excessive waste. Channeling machines have not found favor in Carrara, but for many years wire saws have been used successfully. It is claimed that the wire cuts marble somewhat more slowly than it does Tivoli travertine, in which the average cutting rate is about 5.4 square feet an

hour. Both single and double helicoidal wires are used, the latter having the twist reversed about every 25 meters. Cuts are made at almost all angles; some are nearly horizontal. Front and side joints are utilized to advantage.

One of the most serious quarrying problems is the enormous quantity of waste that has accumulated for many centuries. In early days only the most accessible blocks close to the surface were removed, and waste from new openings covered the remaining beds. Waste piles, locally called "rivers of marble," form one of the most conspicuous features of the Carrara Mountains (see fig. 63). Waste is now carried beyond the limits of future operations, but accumulations of the past are so great

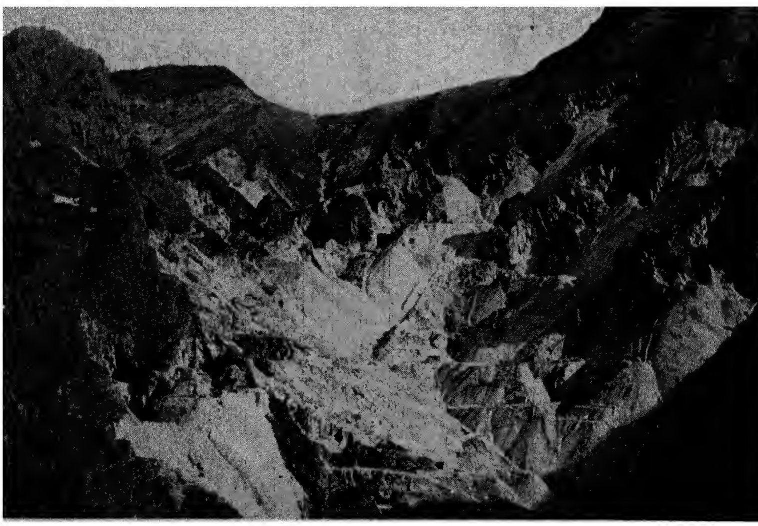

FIG. 63.—General view of the Carrara, Italy, marble district, showing enormous piles of waste. (*Courtesy of J. B. Newsom.*)

in many places that economical removal seems impossible. Since the wire saw was introduced in 1895 waste has been reduced greatly.

Large quarry blocks trimmed and squared with wire saws, hand tools, and hammers are fastened on sledges and taken down the steep mountain side on skidways by special gangs of men known as "lizzatori," or "sliders" (see fig. 64). Soap or oil is put on the skids, and blocks are let down by heavy ropes snubbed to trees or posts along the way. On the north side of Mount Sagro blocks weighing as much as 5 tons are brought down with an overhead cableway. A new rope tramway of 20-ton capacity has recently been completed. It is said to be the largest of its kind in the world, having a span about a mile long as well as several shorter spans.

Marble for export is conveyed from the landing at the foot of the steep slope to the seaports of Avenza and Marina di Carrara by means of the

marble railway (Ferrovia Marmifera). No single event gave greater impetus to the industry than did this railway, completed in 1890 with a total length of 15 miles, including branches.

Over 100 mills are operated at Carrara for sawing blocks into slabs. Three methods are followed. The first and crudest is with an implement somewhat like a common buck saw, though larger, worked by two men; the second and most common is by use of an ordinary gang saw driven by water power, electricity, or steam, sand being used as abrasive; the third method is wire sawing.

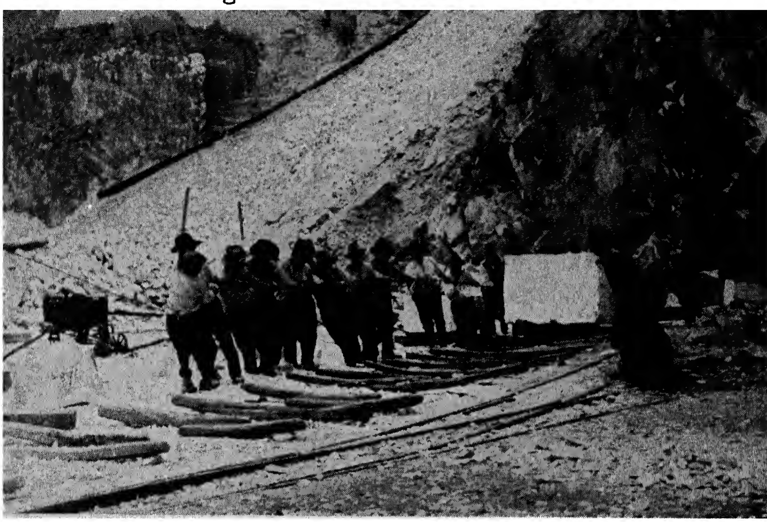

FIG. 64.—Dragging a marble block on greased skids, Carrara, Italy. (*Courtesy of J. B. Newsom.*)

Studios constitute an important feature of the industry. Art in marble working was inspired in the fifteenth century by Michael Angelo, who went personally to the Carrara quarries to obtain blocks for most of his masterpieces. In 1769 Maria Theresa founded the Academy of Fine Arts in Carrara, where many celebrated artists received their early training. Hundreds of little studios or shops are now occupied by men and boys carving ornaments, statuary, and architectural units.

In December 1927 a consortium was established by royal decree under the official title, "Il Consorzio per l'Industria e il Commercio dei Marmi di Carrara." It constituted Government control of rough and sawed marble produced in and about Carrara; the aims were to modernize production, facilitate execution of orders, reduce costs, and promote sales in Italy and abroad.

Other Italian Marbles.—Next to Carrara "Siena" probably is the most popular foreign marble in the American market. The deposit is high in the mountains about three hours' ride from Siena, which is in central

Italy between Florence and Rome. Quarries are small and crudely worked. Blocks are separated laboriously, handled with windlasses and screw jacks in the absence of derricks, rolled down the hill to the roadway, and transported by ox teams to the railway at Empoli about 15 miles away (see fig. 65). Material for export is shipped from Leghorn. The largest quarry, the Convent, produces the highest-priced marble, "Brocatello di Siena" a deep yellow with purple to almost black veins. When the purple veins predominate it is known as "Paonazzo di Siena." Among the most familiar varieties are rich yellow with veins and mottlings of white, pearl gray with yellow veins ("Gray Siena"), and bright yellow with scarcely any markings ("Siena Unie"). They are used prin-

FIG. 65.—A picturesque method of hauling marble in Italy. (*Courtesy of J. B. Newsom.*)

cipally for interior decoration, alone or in combination with other types. About 3,000 metric tons are quarried a year and approximately two thirds is exported. No similar marbles are produced in America, though yellow varieties from France and Algeria are competitors.

Verona and Vicenza colored marbles are obtained from at least 200 quarries, many being underground workings which have supplied stone for the magnificant palaces and public buildings of Venice, Vienna, Budapest, and other cities. Notable varieties are "Verona Red"; "Giallo" (yellow); "Del Torri"; "Brocatello," one of the fossiliferous types; and "Bianco," white with a few light veins, the best known in the markets. With the annexation of Istria in 1919 Italy acquired the valuable quarries of Aurisina, which were worked by the Romans. The marble of this district takes a high polish and is well-adapted to resist weathering. "Botticino," obtained near Brescia, a light cream marble

with slender brown markings, is popular in the United States. The interior of the Grand Central Terminal in New York is an example.

Notable among the Ligurian marbles quarried near the Gulf of Spezia are "Rosso di Levanto," deep red; "Levanto," ranging from purple to red, with dark green serpentine veins; and "Portor," black with gold markings and known in England as "Black and Gold." The best-known Lombardy marbles are the pink and gray, from Val Seriana, and the "Rosso Antico," of Val Brembana. The latter shows a striking combination of blood red, ebony black, gray, dove, and pink. Black marbles are also obtained in this region. Among the Piedmont marbles are "Verde delle Alpi," having a pleasing green-blue color, and "Alpine Black," very little of which enters foreign trade. Umbrian marble was used extensively in decorating the interior of St. Peter's in Rome. Serpentine marbles are obtained at Prato near Florence. Many beautiful marbles are quarried at Abruzzi, Apulia, Calabria, Sicily, and other points in southern Italy, but most of them are used locally only.

France.—France surpasses all other countries in number of varieties of marble produced. In 1888 Blagore[43] listed 240, and since that date many new types have been placed on the market. The color range includes white, black, gray, green, red, brown, and yellow, with striking combinations of two or more colors.

Like the marble industry of Italy that of France dates back to the period when Gaul was a Roman province. Gallic marbles were used for local building and transported to Rome to aid in the decoration of many beautiful structures. Native marbles were employed extensively in France throughout the Medieval Period, the Renaissance, and particularly the reign of Louis XIV, for churches, palaces, mansions, and public buildings. The industry languished in the early years of the Republic until 1835, when it became more active and flourished to the World War in 1914.

Although France produces an abundance and variety of marbles her export trade has been less extensive than that of Italy as the material is used very widely at home. However, during the past few years exports to America have increased materially.

The more important French marbles entering international trade include "Sarancolin," obtained in Hautes-Pyrénées and first quarried in the reign of Louis XIV, a banded and mottled brecciated marble highly esteemed for monuments and interior decoration. Different varieties show combinations of gray, yellow, red, white, and brown in veins and patches. One type of prevailing red with dove patches has been used extensively in Paris, notably for massive decorative columns. "Campan," also quarried in Hautes-Pyrénées near Bagnères, is used for furniture and interior decoration. Several varieties occur in combinations of rose,

[43] Blagore, G. H., Marble Decoration. Crosby, Lockwood and Son, London, 1888.

green ("Campan Vert"), and red ("Campan Rouge"). "Griotte d' Italie," obtained from quarries near Caunes and Felines in Herault, is a high-priced decorative marble. It is one of the French marbles best-known in England, where it is used with black for chimney pieces and clock cases. It has a brown or dark red groundmass with cherry patches and white spots. "Languedoc," quarried at Caunes, is fire red mixed with white and gray. Under the name "Rouge Francais" it has been accorded a place of honor among French marbles and used for notable monumental architecture in France and Italy. "Napoleon," a light fawn stone beautifully marked with pink and brown veins, "Lunel Notre Dame," "Lunel Rubanne" and "Lunel Clair" are obtained from large quarries near Boulogne in the Department of Calais. A company organized in 1905 controls three quarries in the district, the Vallèe-Heureuse, the Basse-Normandie, and the Haut-Banc. Some marbles of these quarries have beautiful flower like markings, hence the appellation "Fleuri." The quarries are equipped with wire saws, hammer drills, and other modern machinery. Wire saws are used also for cutting blocks into slabs. Because of their proximity to Calais and Boulogne an important export trade has been developed.

"Savoie Blue" and "Gilded Savoie," varieties of blue marble obtained from deposits in Savoie, have become prominent during recent years. "Hauteville" is a variety obtained from a rock classed as coral limestone occurring in extensive beds in the Department of Ain. It is fine-grained, is dense in texture, is of uniform light yellow, and takes a very high polish, hence it is classed with decorative marbles. The rock is quarried with wire saws and other modern equipment, and the products are exported in large quantities to North and South America, Australia, and Japan.

Brief generalized statements on the distribution of French marbles by color may be of interest.

The best-known white statuary marble of France is the "Saint-Beat," quarried in Haute-Garonne. It is a uniform, pure, fine-grained stone, obtainable in large, sound blocks. Many years ago it was carved into statuary, vases, ornaments, tables, mantles, and similar articles at the village of Saint Bertrand. White marbles were worked by the Romans in 10 different localities in France, but except for the Saint-Beat none attained prominence.

Black marbles occur in 13 Departments and mixed black and white in 8 Departments, but export trade in them is small. Those of deep black have been quarried in Hautes-Alpes; in Doubs (a variety known as "Le Grand Noir"); at Bize in Haute Garonne; and in various other localities. Probably the best-known black and white marbles are "Le Grand Diable" and "Le Petit Diable," quarried in Aude and at Aubert in Ariege.

French marbles having characteristic red coloring occur in 19 Departments. "Rosso Antico," a blood-red stone with white veins and dots, is a famous variety. "Griotte d'Italie," mentioned previously, is well-known. "Rose Eujugeraie," and "Sarrancolin de L'Ouest" quarried near Mayenne are among the most popular marbles of western France. "Le Rouge Sanguin," "Le Grand Rouge," and a score of others might be mentioned.

"Lumachelle" or shell marbles occur in 14 Departments. They present a wide range of colors and patterns highly prized for furniture, soda-fountain fronts, and interior decoration in England and America. The many varieties are distinguished usually by a descriptive adjective denoting color, for example, "Lumachelle Gris" and "Lumachelle Jaune."

The Cipolin marbles, white with green stripes, are very attractive for use in monumental architecture, interior decoration, and even for statuary. They occur in at least three localities in France, the "Cipolin de Saint-Maurice" in Haute-Alpes; the "Corte Cipolin" in Corsica; and the "Cipolin" in Isere. Both French and Italian Cipolin marbles are well-known in American markets. Marbles from the south of France, well-known during recent years in European and American markets, include "Jaune de Brignoles," "Violetta de Brignoles," "Rose de Brignoles," "Jaune Sainte Beaume," "Jaunes de Molignes," and "Breche Orientale de Pour Cieux."

Many other well-known marbles are quarried in France, but space will not permit reference to them. The best-known varieties are listed in Lent's glossary and in Watson's British and Foreign Marbles and Other Foreign Stones, which are cited in the bibliography at the end of this chapter.

Belgium.—Renwick[44] makes the following interesting statement: "The marble industry of Belgium is a practical illustration of how energetic work and perseverance will enable a country that is far from rich in a particular product to take hold of the material and make the trade therein her own." The marble resources of Belgium are not great, but they have been exploited advantageously, and some of the products, notably the black varieties, have won worldwide reputation. Furthermore, Belgium has some of the largest and best-equipped marble-fabricating plants in Europe, and at least one third of the raw materials are obtained from France, Italy, and other countries. A large foreign trade has been developed, particularly with Great Britain and the United States.

[44] Renwick, W. G., Marble and Marble Working. Crosby Lockwood and Son, London, 1909, p. 79.

The principal deposits are of Devonian and Carboniferous ages. Many of the marbles are unsound and not attractive enough for highly decorative uses; nevertheless, they are worked advantageously for small, low-priced products, such as shop fittings, table tops, sanitary slabs, and chimney pieces.

The most important deposits in Belgium are those producing "Belgian Black" ("Noir Belge") which is regarded as the finest black marble in the world. Four grades are handled—best, second best, common, and inferior. The best grade is the pure deep black variety without veins or markings. The finest grades are obtained northwest of Namur from beds 30 to 40 feet deep, inclined at an angle of 18° and extending about 8 miles. The formation is in layers a few inches to 4 feet thick separated by shale. Rock of best quality is in the lower beds, and most of it is obtained from underground workings. Black marble is also obtained at Dinant in Namur near the French frontier and in other localities.

During recent years fossiliferous marbles have become popular in the United States for soda fountains and other decorative uses. Examples include "Rouge de Rance," with a reddish brown groundmass and large white mottlings; and other reds, such as "Rouge Griotte Fleuri" and "Rouge Byzantine Belge." The Rouge de Rance quarries were reopened in 1900 after being closed for nearly 200 years. Belgium has a great variety of red marbles, which are as a rule sounder than most colored varieties. The red and pink varieties are used extensively for decorative purposes.

"Bleu Belge," quarried near Chatelet, Namur, and various other localities, is a bluish black marble with fine white veins. The "St. Anne" marbles are probably the best known, except for the black varieties, and have the reputation of being among the soundest of the colored marbles of Belgium. The highest quality, dark gray with white veinings and spots, is produced near Biesme and Sougnies, two villages near Charleroi. It occurs in a bed 60 feet wide and is worked at great depth. A second type, lighter in color and with less-attractive veining, is quarried at La Buissière on the Sambre River.

"Petit Granit" is a variety of limestone described in the section devoted to foreign limestones, but certain parts of the deposit, notably those in the Ourthe Valley, are classed as marbles and are used for building in Belgium, France, Holland, and Germany.

Quarry methods and equipment in Belgium are among the most efficient in Europe. Wire saws, compressed-air drills, and electric cranes are widely utilized.

Spain.—Many varieties of marble occur in Spain. Beginning in the north, micaceous rose marbles and others resembling the Cipolinos occur in Galicia. They are available only in relatively small sizes. Green and red marbles are obtained in Asturias. The latter, resembling French

Griotte, was used in such notable structures as the Cathedral of Leon and the Royal Palace in Berlin. Important deposits of black, white, and red marbles, some quite fossiliferous, occur in Guipuscoa and adjoining Provinces. "Grand Antique de Biscaye" is obtained near San Sebastian; and "Estelle Black" and "Verde Molino" in Navarre.

A great variety of colored marbles occurs in the Province of Catalonia. They were quarried extensively many years ago for cathedrals and other important edifices. One, known to the trade as "Tortosa" and consisting of numerous fossils in a red background, is fabricated into small panels, mantelpieces, and clock cases. The Florido quarries, which produce two shades, "Cream Florido" and "Rosa Florido," are among the largest in Spain. They provide material for export to the United States. Gray, red, black, and other varieties occurring near Toledo and Molina in central Spain are used in Madrid and near-by cities.

"Rojo Alicante," and other red and yellow marbles of Valencia and Alicante were worked in ancient times. Important deposits of red fossiliferous marbles are quarried in Cordova and Granada for ornamental uses. Yellow, green, and other marbles from Malaga are of the onyx variety, and some occur as stalactites.

An extensive deposit of coarse-grained white marble occurs in Almeria, southeastern Spain. Production was confined to small workings until 1905, when a British firm began active quarrying. Manufactured marble was shipped from Aguila to various Spanish cities for building. There has been no recent activity.

Portugal.—There are two main centers of marble production in Portugal—Villa Vicosa in the Province of Alemtejo, and Cintra Center, north of Lisbon. "Rose Aurore" is the principal variety obtained in the first district. Quite a variety of marbles are obtained from numerous quarries north of Cintra in the second district. The chief commercial types are "Lioz Bianco," "Lioz Rosa," "Fervenza," "Aimiscado," "Azulino de Maceira," "Vidraco," "Amarelo Negroes," and "Vermelho dos Covoes." Marbles of lesser international importance are quarried in other districts.

Switzerland.—The most important marble of Switzerland is the "Cipolin," quarried at Saillon in the Canton of Valais. It usually consists of a pale green groundmass with straight thin veins of deeper green, but there are many variations. The highest quality, occurring in a bed about 3 feet thick, is named "Grand Antique Cippolino." It takes a good polish and is available in large sound blocks. It is popular in Europe and America, where Greek Cipolin marbles are also used, but little has been quarried since 1925.

Other important quarries are in the canton of Vaud. The St. Triphon quarries of this district produce a black marble with gray and white veining which is used for store fronts and table tops; white gray

and reddish brown stone which is easily worked and takes a good polish is procured from other quarries. A variety known as "Villeneuve" comes in light and dark shades; the latter is much used for tombstones. There were four important producing companies in 1922, two in Vaud and two in Valais. Minor production is obtained from six other Cantons.

Greece.—The fine art of sculpture was developed to a high degree of perfection by the ancient Greeks, whose classic masterpieces serve as models to the present day. The art of carving statuary was no doubt encouraged and promoted because of the availability of high-grade marbles admirably adapted for shaping with tools. In ancient classical Greek architecture marble even was used for roofing. The roof of the Temple of Jupiter Panhellenius on the Island of Aegina and that of the famous Temple of Diana at Ephesus are said to have been covered with white marble tiles.

The most notable of the Grecian marbles are the "Parian," obtained on the Island of Paros in the Grecian Archipelago, and the "Pentelic," quarried on Mount Pentelicus near Athens. Parian marble, which occurs in beds 5 to 15 feet thick, is of delicate, subtranslucent white, and is a little coarser in grain than Carrara marble. With the opening of quarries in the Carrara region the Greek industry practically ceased for 1,500 years. There have been several periods of renewed activity, but present production is limited, the purest material being obtainable in small blocks only. The Pentelic quarries were notable as a source of material for the famous Parthenon erected under the supervision of Phidias during the administration of Pericles, and dedicated in 438 B. C. The quarries lapsed into disuse until 1834, and while they have at times since that date produced large quantities recent production has been moderate. Pentelic marble is of three grades—ordinary, for structural uses; selected, for decoration; and the highest grade, classed as statuary. "Rosso Antico," another famous Grecian marble, is one of the most beautiful red marbles known. "Nero Antico" is a fine-grained black marble widely used in ancient Rome. "Cipollino," a long-established decorative marble, is exported to America. It consists of alternate bands of white and pale green and was named because of its resemblance to an onion cut in half. "Vert Tinos" is another green marble with white zigzag veins. "Vert Antique," a brecciated green serpentine, is probably the original of all the numerous verde antiques quarried in America and abroad, for it was used extensively in ancient Rome and Constantinople. It occurs in three main types—light, dark, and intermediate. "Skyros" appears in several forms; some are light-cream, with variable veining; orange and bright-red veins characterize exceptionally attractive types.

England.—Multicolored fossiliferous marbles of high quality are quarried in Devon, principally at Ashburton, and considerable quanti-

ties are exported to the United States. The prevailing tints are pink, gray, black, and red. The "Red Ogwell" quarry yields marble which in richness of color surpasses many Continental products. Owing to variations in color patterns, quite a variety of trade names is applied; "Plymouth Dove," "Silver Gray," "Devon Siena," "Rose Red," "Spangled Pink," and "Favositidae" are examples. Large, sound blocks are cut from the ledge with wire saws. The quarries are well-equipped and maintain ample stocks. Large finishing mills are operated at Torquay.

Derbyshire marbles, of Carboniferous age, are quarried at Wirksworth. The principal varieties are "Hopton-Wood," a white to gray unicolored marble suitable for exterior building; "Bird's Eye"; and "Derby Fossil." Among other marbles quarried in England reference may be made to "Fosterley," a dark gray fossiliferous variety from Durham; "Purbeck," a light green shell marble quarried near Swanage; and several types in Sussex, Somerset, and Lancashire. A fine-grained, light brown or variegated Carboniferous marble occurs near Beaumaris, Anglesey, Wales; and a black marble, "Poolvash Black," on the Isle of Man. Marble quarrying has not attained importance in England, inactivity being attributed partly to the ready market availability of Belgian and French marbles, and partly to relatively high railroad rates.

Ireland.—Black marbles from near Galway were at one time very popular in London and in foreign countries, but the industry has declined greatly. "Irish Black" is not a solid color; the most popular variety is thickly studded with white shells. "Kilkenny" is another black, decorative marble.

Increased activity has recently been noted in the "Connemara Green" marble quarries near Clifden about 50 miles from Galway. The rock, sometimes called "Galway Green," ranges from light yellowish to dark green with occasional patches of purple and generally is beautifully clouded, mottled, or veined. In the Lissoughter district, opened in 1878, large sound blocks are obtainable, and it is reported that exports attained some magnitude in 1928 and 1929. A red marble is quarried at Shantallow.

Other marbles of a dozen or more district types have been quarried at times in Ireland.

Other European Countries.—Several varieties of marble are obtained in Germany, the best known of which are "Formosa," a multicolored stone; "Green Poppenberg," a green-veined, fawn type; and "Bavarian Green." According to a recent report, an onyx marble is quarried near Gross-Giesen in Hanover for the manufacture of novelties. Fine-grained fossiliferous marbles occur in Austria, particularly in the Tyrol. Marbles are plentiful in Bulgaria. An ancient quarry at Trau, Yugoslavia, has been reopened to obtain stone for the Canadian Government

War Memorial at Vimy Ridge. White and light pink marbles are obtained from well-equipped quarries in Rumania. Here both channeling machines and wire saws are used, the former being preferred, except for opening up and extending quarries. Several quarries, and at least two marble-finishing mills, have been operated in Poland during recent years. A variety from this country exported in considerable quantities since 1930 is known as "Ropocevo" or "Blue-Jaune Caucasian."

Extensive deposits of coarse-grained white, pink, and green marbles are quarried at Dunderland about 150 miles north of Trondhjem, Norway. The rock is difficult to work and polish. "Swedish Green," from near Norrköping, Sweden, is best-adapted for floor tile and interior decoration.

Africa.—Some of the most famous marbles of antiquity originated in northern Africa and were used for statues, columns, tombstones, and ornaments in Rome, southern Italy, and Carthage. The beautiful so-called Numidian marbles were obtained chiefly in Algeria and Tunis. Some quarries were on Mount Filfila on the Gulf of Numidia, and several have been reopened since Algeria became a French province. Available types include a pure white saccharoidal stone used for ancient statuary, also "Blue Turquin," a black variety, and a yellow arborescent marble which has been identified as the original "Numidian" prized so highly by the Romans.

Another celebrated locality is in western Algeria about 20 miles from Oran, where a number of depressions are thought to be old Roman quarries. The absence of debris around the openings may be explained by its possible removal to preserve secrecy regarding quarry locations. The following varieties are obtainable from the rediscovered quarries: "Marmor Bianco," creamy white; "Rosa Carnagione," flesh; "Cipolin;" and several yellow varieties. Beautiful breccias are obtained from a part of the deposit, one of deep red which resembles, if it is not identical with, the celebrated "Rosso Antico." Other reopened Roman quarries in the commune of Arzeu, Province of Oran, revealed a red jasperlike marble, "Rouge Etrusque"; a brownish red variety, "Marbre d' Ain-Ouinkel"; and several others.

Tunisian marbles were used extensively in Roman buildings, and their source was discovered in the last century by a Belgian engineer at Chemtou in the Medjerda River Valley. When the quarries were reopened by a Belgian company an attractive violet breccia was obtained, but the most highly prized discovery was the celebrated "Giallo Antico," which is identical with the stone of that name used abundantly in old Rome. It is yellow, with a beautiful reddish tint, and takes a high polish.

Several quarries are operated in Morocco. Two gray marbles, "Oued Yguem" and "Oqhnika," are obtained near Rabat; also a variety named "Oued Akreuch," which dates back to the Roman period, as

indicated by samples found in the ruins of Chellah. Other Moroccan varieties are "Beige Imperial," fawn-colored, and "Red of Fazi," quarried near Fez.

Other Foreign Marbles.—Marbles occur abundantly in many other foreign countries, but most of them are either undeveloped, are used locally, or are too distant to be of commercial interest. Few, if any, reach the United States. Many beautiful varieties have been quarried in Asia for Government buildings, temples, and palaces, such as the famous Taj Mahal in India. Attractive marble is obtained in Victoria, Australia. Some South and Central American countries report structural and ornamental types. An undeveloped white statuary marble occurs in the Province of Cordoba, Argentina. A highly decorative purple material from the same province, which has been identified as fluorite, is used for the manufacture of novelties. Marbles of many colors, from various parts of Chile, notably in the Provinces of Aconcagua, Los Andes, Antofagasta, Arica, and Magallanes, have been described, but production is limited to a few hundred tons annually for local use. A large deposit of high-grade statuary marble occurs on Cambridge Island, Magallanes. Large deposits are reported at Santa Marta, Colombia; in the Province of Azuary, Ecuador; and in Venezuela. Marble has been produced at Zacapa, Guatemala.

Onyx Marble.—In its true mineralogical sense onyx is a banded form of cryptocrystalline quartz related to agate and jasper. Onyx marble, or Mexican onyx, is a form of calcium carbonate that received the name because it also had a banded structure. This type of marble is deposited from cold-water solutions of calcium carbonate, usually in caves; hence, the name "cave onyx" is sometimes applied to it. Onyx marbles are not uncommon, but large, sound blocks are rare.

The most famous deposits in the world occur within an area of about 500 acres in Lower California, Mexico, at the small town of El Marmol, 330 miles southeast of San Diego, Calif., by road, and 51 miles inland from the Port of Santa Catarina. The largest are on a mesa about 40 feet high, 3,000 feet long, and 1,200 feet wide. The workings are known as the New Pedrara quarries. Commercial onyx occurs in three beds. The uppermost is thin and highly colored, and provides relatively small masses suitable for novelty work such as automobile gear-shift balls, pen bases, lamp fittings, ash trays, book ends, and candlesticks. The second bed is 1 to 2 feet thick and furnishes both novelty and block onyx, and the third or lowest stratum supplies large blocks 1 to 4 feet thick that may be cut into sound slabs for decorative use in banks, theaters, hotel lobbies, and for soda fountains. Explosives are used only in stripping; blocks are separated in the quarry by plug-and-feather wedging. Normal annual production is about 25,000 cubic feet, and a reserve of 1,500,000 cubic feet is said to be in sight.

The most difficult problem is transportation, for blocks must be hauled in 5-ton trucks with trailers 51 miles to Santa Catarina, where storage yards are maintained. Stiff-leg derricks on a 400-foot wharf load the blocks on lighters which carry them to ships lying beyond the breakers. From there they are conveyed to San Diego, where they are manufactured into finished products or held in bonded yards for shipment to many countries.

Mexican onyx is beautifully marked and takes an excellent polish. It has a wide reputation and has been sold throughout the world since 1894. During 1929, 18,687 cubic feet in rough blocks, valued at $78,889, were exported to the United States. Corresponding figures for 1930 were 17,203 cubic feet, valued at $69,120; and in 1937, 13,253 cubic feet, valued at $56,726.

Onyx marbles in France are confined to the slopes of the Pyrenees. The most noteworthy is "Stalactite du Bédat" quarried in Hautes-Pyrénées and manufactured into ornamental objects at Bagnères-de-Bigorre. Famous onyx marbles occur in the Province of Oran, Algeria. There are two main varieties—dark and light. Some varieties are so translucent that they have been used in Paris for lamp shades and for church windows. Algerian onyx was quarried many centuries ago and used for architectural decoration in mosques, temples, and other noble structures. Highly decorative stalagmitic onyx occurring about 10 miles from Constantine, the capital of the department of the same name in Algeria, was quarried by the Romans and is marketed today.

Egyptian onyx, erroneously called "Egyptian alabaster" is one of the most important of the ancient decorative stones. The Egyptians used it from the time of the First Dynasty for sarcophagi, for interior decoration in temples, and for vases and other objects. Many deposits were worked in the Nile Valley of Upper Egypt, but most of them have been worked out or abandoned for other reasons. Recent supplies are obtained only near Assiut, the site of ancient Lycopolis.

Translucent onyx marbles, with attractive green, brown, and red veinings, occur at several points in Argentina, principally in the Provinces of San Rafael, Mendoza, and San Luis. They are used for making objects of art, such as cameos and statues, and for architectural purposes, chiefly for interior decoration of large public buildings. Exports range from 50 to several hundred tons annually and in 1924 reached a high figure of 585 tons. France, Belgium, Italy, and Germany were formerly the chief destinations, but much of the onyx now reaches the United States (see table page 317). It is sometimes erroneously called "Brazilian onyx." Onyx production has been reported from the Province of Atacama, Chile.

In Hanover, Germany, an onyxlike mineral locally named "onysette" is being worked in a small way to produce blocks which are manufactured

in both Germany and Holland into office ornaments, clocks, cigar boxes, and other novelties. At first the deposit was quarried by blasting, which caused excessive waste, but more recently cutting and wedging methods have been used, and larger, sounder blocks are produced.

FOREIGN SLATES

Slates from foreign countries have never attained a strong foothold in American markets, as values of total imports range only from $50,000 to $100,000 annually. Nevertheless, long-established, important slate industries in several European countries are potential, if not actual, competitors.

Canada.—Slate deposits of commercial importance in Canada are confined to the eastern part of Quebec. Black slates suitable for roofing material are best-known in the counties of Richmond, Missisquoi, and Temiscouata, but the roofing-slate industry has stagnated during recent years. The quarry that has produced most consistently was opened in 1868 at New Rockland, Richmond County, where the slate occurs in a belt about 200 feet wide dipping 70 to 80° and with vertical cleavage. Quartz veins are present in places. Recently a deposit of green slate has been worked on the same property. Black slates have been produced at times near Corris and Asbestos. In 1922 a black-slate quarry was opened at Mystic about 50 miles southeast of Montreal.

In 1908 a large deposit of black slate was uncovered during railway construction near Glendyne in Temiscouata County about 120 miles from the city of Quebec. Slaty cleavage and bedding dip about 24°, and quarry conditions are favorable. Substantial production was maintained until 1915 when the plant was destroyed by fire, and there has been no subsequent activity. Red and green slates have been found in several places; utilization for roofing purposes has been negligible, but two plants are in operation for the manufacture of granules.

Wales.—The slate industry of Wales stands in the forefront among all slate-producing industries of the world; it has the largest excavations, employs the most men, and produces the greatest tonnage of finished products. There is evidence that the Welsh deposits were worked as far back as the Roman occupation; but as an important industry, slate production dates from the closing years of the eighteenth century. In 1925 North[45] stated that about 60 slate mines and quarries were in active operation.

In Wales slate occurs in five important areas:

1. In Carnarvon, in beds of Cambrian age; this area comprises the important districts of Bethesda, Llanberis, and Nantlle, of which the two most famous quarries are the Penrhyn and the Dinorwic. The Bethesda slates are shipped from Port Penrhyn, Bangor; those of Llan-

[45] North, F. J., The Slates of Wales. Univ. of Wales, Cardiff, Wales, 1925, p. 50.

beris from Port Dinorwic; and the Nantlle slates from Carnarvon. The slates are reddish purple, blue, or green and lie in a formation 500 to 1,000 feet thick.

2. At Blaenau Festiniog in Merioneth, in rock of Ordovician age, where the slates are blue or gray, have a lustrous surface, and are finer-grained than those of the first area. They are obtained from underground mines, the best-known of which are Croesor, Llechwedd, Maen Offeren, Manod, Oakeley, Votty, and Bowydd. Portmadoc is the point of shipment for this region.

3. Between Towyn and Corris, where slates of both Ordovician and Silurian age are available; this district includes a series of fine-grained homogeneous slate rocks about 1,500 feet thick. Two important beds, known as the Broad Vein and the Narrow Vein, are quarried wherever the cleavage is sufficiently well-developed. The products are shipped from the ports of Towyn and Machynlleth.

4. In the country between Llangollen and Corwen, where slates are quarried or mined principally at Moel Ferna, Glynceiriog, and other points near Corwen.

5. Slate of Ordovician age in the Prescelly district of Pembroke and adjacent parts of Carmarthen. That from the Glogue quarries is bluish gray, while near Prescelly (Maenclochog, Llandilo, and Gilfach quarries) it ranges from olive green to silvery gray.

The two most important producing districts are Blaenau Festiniog in Merioneth, where production is from underground mines and the Bethesda-Llanberis area in Carnarvon where it is mined from open quarries.

The largest mines at Festiniog are the Oakeley, Greaves, Votty, and Maen Offeren, which together have about 130 miles of tramway tracks. There are five beds of commercial slate ranging from 26 to 126 feet in width and dipping 30 to 45° into the mountain. They are known locally as the New Vein, Old Vein, Small Vein, Back Vein, and North Vein. Slaty cleavage dips at a steeper angle than the beds and therefore crosses them diagonally. A bed of chert 5 to 10 feet thick over the New Vein forms a good roof. An inclined shaft is sunk just beneath it, from which levels are driven along the strike and also north and south to open up other veins. From these drifts good slate is removed; chambers 30 to 45 feet wide and 40 to 50 feet high are thus formed, pillars of equal width being left between them for roof support. Chambers are worked out at deeper and deeper levels, the depth between floors ranging from 50 to 70 feet. In one mine the depth of the workings from the highest to the lowest floor is over 1,400 feet. A few years ago it was reported that the quarry had 50 miles of railroads, 4 miles of pump mains, and 12 miles of compressed-air mains. Slate had been removed from 26 levels, work being carried on at different levels simultaneously. The

chambers are among the largest and most numerous in any underground operation in the world. The mines are electrified and well-equipped. Slate blocks, roughly trimmed in the pits, are hauled up an inclined shaft by cableway in wagons of about 2½ tons capacity and conveyed to sawing and dressing sheds. The problem of waste is serious, the proportion being 10 to as high as 30 tons for 1 ton of good slate.

The Penrhyn and Dinorwic quarries are good examples of the open-pit terraced type; in fact, they are among the largest quarry workings in the world. Before 1793 the site now covered by the Penrhyn quarries was worked by numerous independent men, each paying an annual rental of £1 or £2, but in that year Richard Pennant obtained possession and worked the district as a unit. The force of 150 men was increased to 600 in 1808 and to 3,000 in 1880. Through these many years of activity a remarkable series of steplike ledges or terraces each about 70 feet high, has been developed; the topmost stands at a height of about 1,800 feet on the shoulder of the mountain. At a distance they resemble the great open-pit iron mines of Minnesota, except that they extend up the mountain sides rather than sink in great depressions. Work proceeds simultaneously on each terrace. Slate blocks are separated by drilling and wedging or by light charges of powder. Neither channeling machines nor wire saws have been used successfully in Welsh quarries or mines. Rough blocks are trimmed on the terrace floor and removed laterally by tram cars. Other open quarries are in the form of great pits 300 to 500 feet deep, some of which are also terraced.

Roofing slate is the chief product of Welsh quarries. Splitting is done by hand and trimming usually by power-driven rotary trimmers similar to those used in Vermont. Originally all slates were of one size, about 11 × 5½ inches, but about 1735 a second size called "doubles," approximately 13 × 7 inches, was produced. Later other sizes were introduced and given the fanciful names "ladies," "countesses," "duchesses," "princesses," and "empresses." The last mentioned were the largest, measuring about 26 by 16 inches. Slates are now made in a great many sizes comparable with those established in the United States, and, as in America, different markets have different requirements as to size. Roofing slate is sold by the mille (1200 pieces) rather than by the square. Welsh slate is used to a limited extent for flagging, billiard tables, cisterns, dairy and laboratory tables, electrical switchboards, and school or "writing" slates, as they are called in Wales.

Welsh slate has an extremely low porosity and is remarkably resistant to acids and weathering agencies. It has won worldwide reputation for service and before the World War had very extensive foreign markets. The industry was practically paralyzed during the war but has recovered to some extent. In 1931, 27 active companies were listed. Very little Welsh slate reaches American markets.

England.—Slate has been quarried for many centuries in England from the upper Devonian rocks of Cornwall, and years ago it had an extensive continental trade. Quarries are numerous in this district, but the Delabole in St. Feath and the Lamb's House at Tintagel are the only large ones recently operated. The slate is blue-gray, lighter in weight than Welsh slate and very durable. A limited quantity of rustic red is available. Well-equipped mills for the manufacture of structural products are operated at Delabole. Devonian and Carboniferous slates have been worked in a small way in Devon. Some weather to dull brown and are used where a rustic effect is desired.

Slates from the Silurian and Devonian rocks of the English Lake district split less easily and in thicker slabs than Welsh material and therefore produce fewer slates per ton of rock, but the product is very durable. Green slates are obtained at Keswick, Cumberland. The roof of Cockermouth Castle, covered with Cumberland slate about 1750, is said to be in excellent condition. The Caudale roofing slate quarries of Westmorland operated more than 100 years ago but idle since 1914, were reopened in 1933. Underground methods are employed. High-quality gray-blue roofing material is quarried near Kirkby-in-Furness, northern Lancashire.

Slate of Cambrian age is quarried at Sulby near Ramsey on the Isle of Man.

Ireland.—Greenish Devonian slates from Valentia Island, County Kerry, are well-suited for flagging and were shipped to England before the Welsh flagging industry was developed. Quarries in Tipperary County opened as early as 1826 were worked extensively, and about 700 men and boys were employed in 1845. Although the industry has declined to some extent, it is still active and in 1927 employed 120 men. Quarries and mills are well-equipped; slabs are cut to length with diamond saws. The slate rock, of lower Silurian age, is hard and blue-gray. About 75 per cent of the production, chiefly roofing slate, is sold in Ireland and 25 per cent in Scotland. Other districts where slate is or has been produced include Ross Carberry and Bantry, Cork County; Shillelagh, Wicklow County; and several places in Wexford, Waterford, and Clare Counties. Local slates have been used quite extensively for roofing and to some extent as building stone in southern Ireland.

Scotland.—In Scotland slate is quarried in Argyll, Perth, and Dumbarton Counties from rocks of Ordovician age. The most important quarries are in the black-slate belt on the west coast of Argyll. Quarries at Easdale, an island in the Firth of Lorne, have been operated more than 200 years. Numerous crystals of iron pyrite are present, but they are unusually resistant to weathering, retaining their original luster on roofs that have been exposed for more than a hundred years.

Renewed activity in the ancient slate quarries at Ballachulish on the mainland in northern Argyll was in prospect early in 1933.

France.—An important slate industry has existed in France for many years. The larger quarries are situated in six widely separated districts:

1. Angers, western France, where numerous large workings are to be found. There are four principal slate veins of Ordovician age, designated the "northern," "southern," "intermediate," and "extreme southern." They stand at angles at 60° to the vertical and extend to great depth. They are mined separately because the veins have barren rock between them. At Angers slate is mined underground through vertical shafts, and an ingenious method of overhead stoping is employed. A shaft is sunk to considerable depth, possibly 800 feet, lateral drifts are projected, and slate is broken down from the roof. Good slate is hoisted out, and waste remains on the floor, which is gradually built up to keep pace with upward extension of the roof. This method, designated "Blavier," was first introduced in 1877, and it is claimed that two thirds of the entire production of France is mined in this way or in some modification of it. The same method was introduced later at Monson, Me. Farther west in the same belt the rock is greatly jointed, and open-pit work is followed. Angers slate of best quality is a strong, tough, blue-gray product, about 98 per cent of which is used for roofing, mostly in small sizes. The quarries and mines are well-equipped with the most modern machinery. Wire saws are used extensively.

2. Finisterre in the extreme northwest, at the western outpost of the same series of metamorphic rocks that occur at Angers. Several large quarries are situated conveniently for export trade.

3. Ardennes in the northeast. Highly metamorphosed slates of this district are of Cambrian or pre-Cambrian age and more variable in structure and color than in most areas. Fumay furnishes a micaceous chloritic slate containing siderite crystals. At Revin south of Fumay it is black, "Veine des Peureux." Slates at Deville are green, gray-green, and blue and contain magnetite. At Saint Anne they are blue, red, green, and violet, extremely fissile, and very durable. Workings throughout the district are chiefly deep underground mines, the products of which have easy access to Belgium and Holland by way of the Meuse River and to many points in France by canal and railway. About 85 per cent of the product is used for roofing, and most of the remainder for electrical panels and switchboards.

4. Correze, in central France, where a small output of slate is quarried.

5. The Pyrenees, in the extreme south, where slates occur in many localities. The principal quarries are near Bagnères-de-Bigorre and Lourdes. Transportation conditions are less favorable than in the districts previously described. Details of the method of using wire

saws in underground chambers at Labassère, Hautes Pyrénées, have been described by Delcourt.[46]

6. Savoie, in the southeast near the Italian frontier. Here slates occur in rocks of various geologic ages ranging from the old crystallines to Carboniferous. They contain more lime and alumina than most slates and tend to whiten with age. The numerous quarries of the district fall into four main groups: (*a*) Saint Jean de Maurienne and Saint Colomban-des-Villards, which is the southernmost and chief operation; (*b*) the center district; (*c*) the northern Flumet quarries; and (*d*) Upper Savoie, including Morzine, Montriond, and Houches quarries. Slates of best quality are obtained from the center district.

The Angers and Ardennes beds are the most important, together yielding about 70 per cent of the total production of the country. French slates are used primarily for roofing, and on an average less than 1 per cent is employed in slab form. Before the World War France had a large export trade to other European countries and to South America. Since that time exports have decreased very greatly owing to requirements of the reconstruction areas. A small but increasing amount reaches the United States.

Belgium.—The Belgian slate industry is centered at Neufchateau and near Martelange in the Province of Luxemburg. In the latter region beds dip about 55° and are worked underground. The side walls of chambers are cut with wire saws. Recovery of good slate is said to be as high as 25 per cent of gross production. Products of the mines, some of which have been in operation since 1784, are used chiefly for roofing, with minor quantities for billiard tables and other slab work; a highly siliceous variety is used for whetstones. The industry was paralyzed during the World War but has recovered to some extent. Recovery approaching former activity is doubtful because of the increasing difficulty of working in deep mines and the threatened exhaustion of available supplies.

Luxemburg.—Two large mines are in operation near Martelange, a town on the border between the Province of Luxemburg, Belgium, and the Grand Duchy of Luxemburg, a position which accounts for reference to the town under both countries. The slate is in nearly vertical beds, curving back and forth at steep angles which necessitate working in underground mines, now about 300 feet deep. The chief product is roofing slate, with a minor output of structural slabs. Between 300 and 400 men are employed, and annual production averages about 10,000,000 slates, ranging in size from 6 by 9 to 14 by 20 inches.

Portugal.—A slate deposit about 4 miles long and ¾ mile wide is situated at Vallong about 11 miles northeast of Oporto. It is worked to a

[46] Delcourt, E., A Scientific Method of Quarrying Slate. Quarry and Surveyors' and Contractors' Jour., vol. 27, no. 300, 1922, pp. 52–56.

depth of about 100 meters; quality deteriorates below this point. Beds stand at angles of 80 to 85°. The slate, which is dark blue-gray, is graded as first and second quality. When free from iron pyrite it is said to be an excellent electrical slate, but much of it contains this mineral and therefore can be used only where a low-voltage current is employed. Products manufactured include roofing slate, bricks, slabs, electrical panels, billiard-table tops, school slates, and pencils. From 85 to 90 per cent of the production is exported, increasing quantities reaching the American market.

Spain.—Slate is produced chiefly in the Provinces of Badajoz and Guipuzcoa, with minor production in Coruna, Guadalajara, Lugo, and Zamora. In 1929 the industry employed 156 men and produced slate valued at 682,957 pesetas.

Italy.—From 85 to 95 per cent of all Italian slate is obtained in the Province of Genova, and the largest quarries are near Cicagna. This slate is used for roofing, blackboards, billiard tables, and electrical panels. Export trade in slate to other European countries has declined greatly during recent years in all branches except billiard tables. Italy is the most important foreign source of supply of slate entering the United States, and imports during recent years have ranged in value from $17,000 to $43,000. The unit value of Italian slate sold in America is higher than that of similar products shipped elsewhere; this may be due partly to the shipment of higher-grade products and partly to trade in semimanufactured rather than in crude blocks. Practically no roofing slate is shipped to America, as it would not endure in the climate. It is claimed that Genova roofing slate will deteriorate in two years in England. Some Italian blackboard slate reaching the United States has been found on analysis to contain about 40 per cent calcium carbonate.

Germany.—Slate is mined principally in the Hunsruck and Eifel regions, on the Moselle, on the Rhine, in Westphalia, and in Saxony. As much of it occurs in beds with a steep dip and nearly vertical cleavage, underground operation is necessary. An overhead-stoping method similar to that used at Angers, France, has been introduced. German slate is used for roofing, for floors, steps, and other structural purposes, for billiard tables, electrical panels and switchboards, and for school slates. Very small quantities reach America.

Switzerland.—Commercial slate quarries are operated in the Cantons of Bern, Glarus, Saint-Gall, and Valais, the principal quarries being in the last two named. Both underground and open-pit mining methods are used. Since tile is replacing slate as a roofing material in Switzerland, slate has been diverted to some extent to slab uses, such as billiard tables, school slates, sanitary applications, and flagging.

Norway.—Thick, heavy, architectural slates, which are relatively coarse-grained and resemble mica schists are quarried by one large

company near Bergen. Small knots of silica give the appearance of bird's-eye maple, and the surfaces show many attractive colors. The stone is well-adapted for ornamental flagging or for heavy roofs of large structures.

Sweden.—The best slate of Sweden, comparable in quality with that from Wales, is quarried at Kellsvik near Lake Wena. Thick, heavy slates are obtained in several other localities.

Australia.—Slate deposits have been developed near Tenterden, Western Australia, but even the stimulus of a Government bonus has failed to promote extensive production.

India.—Several thousand tons of slate are produced annually in India. Production is centered in the Kangra district of the outer Himalayas; near Rewari in the Gurgaon district south of Delhi; and in the Kharakhpur Hills, Monghyr district, Bihar. The slate is used for roofing and flagging, for small dishes and curry platters for native use, and, with enameled surfaces, for electrical purposes. According to report, a school-slate industry was established a few years ago in the last district, with a monthly production of 22,000 framed slates.

Union of South Africa.—The only important slate operation in South Africa is near Zwartruggens, Transvaal, about 100 miles northwest of Johannesburg where, according to reports received by the writer in 1928, a flourishing industry has been established. Marketed products include blackboards, and roofing, structural, and electrical slate.

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CHAPTER XIV

MISCELLANEOUS ROCKS AND MINERALS USED FOR BUILDING AND ORNAMENTAL PURPOSES

Quite a variety of minerals and rocks not included in any preceding classifications is used for structural purposes or for decorative effects. Most of them are employed in small amounts but are interesting because of their special adaptations or striking ornamental qualities. Those briefly described include the more important minor materials used for building purposes, interior decoration, furniture, or novelties, but precious and semiprecious stones fall outside the scope of this book.

Agalmatolite.—The name agalmatolite is given both to massive talc and massive pyrophyllite (a hydrous silicate of aluminum and potassium) but more properly is applied to the latter. There is evidence also that some of the material designated agalmatolite, which was used for ancient carving, consists of pinite, also a hydrous silicate of aluminum and potassium closely related to muscovite, possibly a massive form of that mineral. Agalmatolite, also termed "lardstone," "figure stone," and "pencil stone," is soft and waxy and is used for carving, chiefly by the Chinese, into ornamental dishes, miniature pagodas, and grotesque images. It occurs in Saxony and China.

Large quantities of pyrophyllite occurring near Hemp, N. C., are pulverized and used in the same way as talc. While some was used in massive form many years ago for gravestones, chimneys, fireplaces, and stove linings, apparently none of it possesses adaptability for carving comparable with the Chinese product.

Alabaster.—Alabaster is a massive, fine-textured form of gypsum, which has the composition $CaSO_4 2H_2O$—a hydrous calcium sulphate. Gypsum is a very common mineral, and large quantities are calcined to make plaster of paris, which is widely used as finishing plaster and for many other products. A very small amount is employed in massive form. It is usually white; and, as its hardness is only 2 in Moh's scale, it may be cut and carved easily with knife or saw.

Pink to white alabaster of good quality has recently been quarried near Fort Collins, Larimer County, Colorado, and manufactured into lamps, urns, vases, bowls, jars, pen stands, book ends, and other novelties. There has been little or no production of alabaster elsewhere in the United States although it is reported in several localities.

The alabaster industry has been developed most fully in Italy, where high-quality material occurs in several localities, chiefly in Tuscany and Piedmont. Clouded and veined varieties are obtained near Volterra, and pure white alabaster principally near Castellina. Here it was used in ancient times for making carved sarcophagi in which the ashes of the deceased were buried in the mountain sides. The deposits have been worked for more than 2,000 years. The alabaster occurs in smooth, ovoid masses up to 3 or 4 feet in diameter irregularly disseminated in beds of marl or clay. In recent years wire saws have been used for cutting out blocks to avoid the fracturing caused by blasting. Alabaster working for the production of miscellaneous articles was until the last decade a hand-carving process conducted by small groups of artisans residing in Volterra, Florence, and Pisa. Keen competition was encountered with French and German workers, who employed machinery to take the place of hand carving; and in consequence, lathes, sawing machines, and other types of mechanical equipment were introduced in Italy about 1920. A modern factory consuming about 5,000 tons of alabaster a year was erected at Leghorn in 1927. The products of this factory include statuettes, lamp shades, pedestals, vases, and various novelties. Lamp shades and some other products are artificially colored.

Statuettes, vases, and novelties carved in semitransparent alabaster are hardened and rendered opaque by being placed in cold water, which is slowly raised to the boiling point and allowed to cool. Thus, they are made to resemble Carrara marble and often are sold as such. Recent production in Italy has been entirely from the Volterra-Florence region. Manufactured alabaster valued at about $50,000 is exported to the United States annually.

Good-quality alabaster occurs in gypsum deposits near Paris, France, but is used much less extensively than in Italy. Beautiful white alabaster is reported from the Provinces of Guadelajara and Saragossa, Spain. In England alabaster was quarried many years ago at Chellaston, Derbyshire, and at Hanbury, Staffordshire. Alabaster said to have been obtained in Devonshire was used for bank counters in New York many years ago. Alabaster is also obtained in Rumania and Egypt.

Amazonite.—Amazonite, or Amazon stone, is a green variety of microcline, a potash feldspar. Deposits are reported in the Ural Mountains of Russia; near Antsirabe in Madagascar; on the east coast of James Bay, Canada; and at Florissant near Pike's Peak, Col. It is produced commercially for cutting and carving and for concrete facing at Chula and Amelia Court House, Va.

Catlinite.—Catlinite, also called "Indian pipestone" because it was used by the Sioux Indians for carving pipes and other articles, is a form of indurated clay of variable composition. It is dull red, sometimes flecked with yellowish dots. The most notable deposit is near the town of Pipe-

stone, Pipestone County, in southwestern Minnesota, where it occurs in a bed about 18 inches thick interstratified with Sioux quartzite. Tomahawks and other novelties carved from it are sold at Pipestone. Indians frequently visit the deposit to obtain stone for use in their ceremonies.

Clay.—Houses with clay-rammed walls have been constructed both in Europe and in America. According to report, they have endured in England for over 100 years. Sod huts and adobe dwellings are among the earliest types of human habitations.

Diatomite, Tripoli, and Pumice.—Both diatomite and tripoli are used chiefly in pulverized form; however, massive diatomite, particularly that occurring at Lompoc, Calif., is sawed into bricks or blocks for furnace lining and to a small extent for light-weight building material. It has been used as a building stone in southern California. Massive forms of both diatomite and tripoli are shaped into filter blocks. In Japan block pumice is used for the construction of earthquake-proof houses.

Fluorite.—Small fragments of the mineral fluorite (CaF_2) are used in large quantities as a flux in steel furnaces, and in granular or pulverized form it is employed in many other ways. Perfect transparent crystals are used in certain optical instruments. Fluorite as a structural or ornamental material is unusual, but a notable example of such use in the Province of Cordoba, Argentina, has been recorded. Here it may be obtained in blocks sufficiently large and sound to be cut into slabs for panel work, or to be used for columns or bases, and its color combinations of purple, green, and amber with varying shades in transmitted and reflected light make it a beautiful stone for such decorative uses. Most of it, however, is carved into novelties and jewelry. Because of its resemblance to lapis-lazuli it has been named "litoslazuli." A variety known as "blue John," obtained in Derbyshire, England, is made into novelties and ornaments. The Indians used fluorspar obtained near Rosiclare, Ill., for carving ornaments.

Jade.—Material known as jade includes two minerals, nephrite and jadeite, the former being the more common. Nephrite is a monoclinic amphibole having a composition expressed by the formula $Ca(MgFe)_3(SiO_3)_4$. It has a hardness of $6\frac{1}{2}$ and is therefore nearly as hard as quartz. Colors range from white to leaf green and dark green, the green shades being due to the presence of ferrous iron. Jade knives and other implements have been found in prehistoric ruins, such as the Swiss lake dwellings. The Chinese are masters in working this very hard and tough mineral, and their delicate, intricate carvings are highly prized among collectors. Merrill[47] refers to a white jade object in the Indian museum, London, which required three generations of workers 85 years to complete. The great seal of China is carved from jade. The mineral

[47] Merrill, G. P., Stones for Building and Decoration. 3d ed., John Wiley & Sons, Inc., New York, 1910, p. 349.

occurs in China, Turkistan, Siberia, New Zealand, Alaska, and British Columbia, Canada. Jadeite, a monoclinic pyroxene, resembles nephrite very closely and is used in the same way. The most important locality for jadeite is the Mogaung district of Upper Burma.

Labradorite.—An iridescent variety of plagioclase feldspar has been named "Labradorite" because of its occurrence at Paul's Island on the coast of Labrador. Undeveloped occurrences have been noted in the Province of Quebec, Canada. A rock containing an abundance of this type of feldspar occurring near Laurvik, Norway, has been named "Laurvikite," and is used widely as an ornamental syenite. It has been described previously under the granites of Norway.

Lapis-lazuli.—Lapis-lazuli is not regarded as a homogeneous mineral, but rather as an intimate mixture of several minerals; the chief of these, lazurite, gives it a rich blue color. On account of this color lapis-lazuli is much in demand for ornamental inlaid work, but as it is costly it is usually employed only as a thin veneer. Large vases of lapis-lazuli are on display in the Vatican Museum, Rome. Commercial supplies are obtained in Afghanistan, Siberia, and China, and samples have been obtained in San Bernardino County, California. It was mined in the Province of Antofagasta, Chile, from 1852 to 1896 when operation ceased. A deposit of several thousand tons of high-grade material has been reported in the Province of Coquimbo, Chile.

Malachite and Azurite.—Malachite is a green hydrous carbonate of copper, $CuCO_3Cu(OH)_2$, occurring above ground-water level as an alteration product of copper-bearing sulphide ores, occasionally in masses large and compact enough to be used for ornamental purposes. Small pieces are used for vases and ornaments, while the larger masses are sawed into slabs for table tops, panels, bank counters, and similar products. The most noted source of malachite is Nijni Tagilsk in the Russian Urals, where like cave onyx it occurs as stalagmites with beautiful bandings in various shades of green. Solid blocks 3 feet thick have been obtained. Two malachite altars in the church of Saint Paul Outside the Walls, Rome, were a gift of one of the Russian czars. Large masses have been found also in the Burra Burra Mine near Adelaide, Australia, and in the copper mines of Arizona.

Azurite is a blue hydrous copper carbonate having the composition $2CuCO_3.Cu(OH)_2$. It occurs in large masses less commonly than malachite but may be interbanded with it, forming a very striking and beautiful combination of concentric green and blue bands.

Meerschaum.—Meerschaum, or sepiolite, is a hydrous magnesium silicate occurring in compact, granular, nodular, or earthy form, usually as an alteration product of magnesite or serpentine. When pure and dry it is light enough to float on water. The best-known deposits from which most of the commercial material originates are in Anatolia, Asia Minor,

about 120 miles southeast of Istanboul (Constantinople). Deposits have been reported in the Islands of Euboea and Samos, Greece; near Hrubschitz, Czechoslovakia; in Bosnia; in Morocco; and near Vallecas, Madrid, and Toledo, Spain. It occurs in the United States in Grant County, N. M.; Chester and Delaware Counties, Pa.; Westchester County, N. Y.; Duchesne County, Utah; and at the Cheever Iron Mine, Richmond, Mass. American deposits have little, if any, commercial importance. The principal use is for carving into smoking pipes and cigar or cigarette holders. Since 1767 the greater part of the carving industry has been centered at Ruhla in the Thüringian Forest, Germany.

Mica Schist.—Fine-grained mica schists quarried in Grafton County, N. H., are used for the manufacture of whetstones and other abrasives. Garnet, rutile, and quartz crystals provide the cutting surfaces. Similar rock is quarried from adjoining deposits in Orleans County, Vt.

Porphyry.—Porphyry is a volcanic rock consisting of crystallized minerals scattered throughout a fine-grained groundmass. A notable decorative rock of this type is the red porphyry of upper Egypt, described by Pliny. White and light pink feldspar crystals are set in a groundmass which owes its dark red color to the presence of piedmontite. It occurs in a dike 80 to 90 feet thick and is obtainable in large blocks. It was widely used by the Romans for columns, baths, sarcophagi, and statuary. Difficulties of transportation have discouraged recent development.

Green porphyry from the Province of Laconia, Greece, also was used by the ancients. It consists of a dark, olive green groundmass sprinkled with light green feldspar crystals and small bluish agates. It has rarely been used in modern decorative work.

Quartz.—Various ornamental forms of quartz, such as agate, onyx, jasper, and heliotrope, are to be regarded as semiprecious stones rather than structural materials. Fossil wood, also called petrified or agatized wood, sometimes occurs in large masses that are cut into slabs and polished for very beautiful table tops, panels, and novelties. It is very expensive to work on account of its hardness. Apache County, Ariz., is the district most noteworthy for fossil wood.

Flint is another form that has uses other than as a semiprecious stone. It was one of the earliest minerals worked by man for the manufacture of arrowheads, skinning knives, and implements of war.

Snow and Ice.—The mineral substance water (H_2O), which solidifies as snow or ice at temperatures below 0°C., finds some use as a structural material. Such use is confined chiefly to areas between the Mackenzie River in Canada and the Atlantic Ocean (except in parts of Labrador) where the Eskimos dwell in igloos or dome-shaped snow houses. An important feature of Canadian winter sports is an ice carnival, for which it is customary to build a palace entirely of blocks of ice. Log cabins in the Far North are sometimes coated with ice to make them weather-

proof. When the winter season has advanced to a point when freezing weather is practically continuous water is thrown over the cabin walls and allowed to freeze. A coating of any desired thickness may be obtained by repeated application of water.

Sodalite.—Sodalite is a silicate of sodium and aluminum containing chlorine. A beautiful blue variety occurs in the northern part of Hastings County, Ontario, Canada. It is claimed that sodalite-dotted rock may be obtained in blocks 4 feet square and almost pure sodalite in smaller pieces. A shipment of 130 tons was sent to England in 1906 and used as decorative material in a London residence. The high proportion of waste and the difficulty of working the rock have discouraged further development. Occurrences of the mineral in small masses are reported from Ice River, British Columbia, Canada; the Ural Mountains; Mount Vesuvius; Norway; and Litchfield, Me.

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CHAPTER XV

DETERIORATION, PRESERVATION, AND CLEANING OF STONEWORK

DETERIORATION OF STONE

Effects of Time on Stone.—Nothing in nature is immune from change. Outcrops of rock bearing unmistakable glacial striations showing that they have been exposed for countless years may present little evidence of decay, but careful examination will undoubtedly reveal the beginnings of alteration. Some rocks decay with comparative rapidity. Therefore, endurance is a very important quality of building stone, particularly in regions where weather conditions are severe.

The use of stone as a structural material in America is comparatively so recent that architects, builders, and engineers have not been faced generally with serious problems of deterioration. Few of our oldest structures are more than 200 years old, and most of them have stood for less than a century. In the Old World many stone structures date back at least 1,000 years and in the even climate of Egypt several thousand years more, but gradual physical or chemical changes have led in some instances to a degree of deterioration that demands attention. In England decay of building stones has become a matter of such concern that in 1923 a Government committee known as the Stone Preservation Committee was formed to investigate fully the subject of their deterioration and preservation.

Because of the kaleidoscopic changes of modern civilization many buildings in America are designed to stand for periods not exceeding a quarter of a century. However, monumental structures, cathedrals, shrines, and public buildings of many sorts should be built for future ages as well as for the present. Fortunately, architects of our greatest structures are exercising commendable foresight and are using only those materials and designs that will endure for centuries. The Washington Cathedral, for example, is being built to stand with little need of repair for many hundreds of years. It is significant that the architects use very little metal, except in roof supports, which are easily replaceable; foundations, walls, and towers are of solid masonry embedded on native rock.

Agencies That Cause Change.—Disintegration of rock involves complex processes, some of which are not well-understood; but its importance to the stone industries is so great that a brief discussion of the principles

governing decay is justified. More detailed data are presented by Warnes and Schaffer (see bibliography at the end of this chapter).

Agencies that bring about deterioration in rocks are both chemical and physical. They may be of external origin entirely, or their effects may be intensified by reactions within the rock itself. The chief causes of deterioration may be classed as follows:

- Reactions chiefly chemical
  - Solution
  - Alteration and replacement of minerals
- Changes or agencies chiefly physical
  - Expansion and contraction
  - Frost action
  - Abrasion
  - Settlements
- Causes both chemical and physical
  - Plant growth
  - Marine borers
  - Faults in accessory materials and workmanship

The foregoing causes of deterioration are considered in order in following paragraphs.

Reactions Chiefly Chemical. *Solution.*—The solubility in pure water of practically all building stones is very slight. Rain water, however, is rarely pure, for it dissolves gases from the air through which it falls, and also various compounds that are present in soot and grime carried by winds and deposited on buildings. One of the most common solvents is carbon dioxide gas (CO_2), which is always present in the air in some amount. In country atmosphere it may not exceed 60 parts per million, while in towns and cities, as determined by Warnes,[48] it may reach 450 parts per million. Carbon dioxide is a product of combustion of fuels, therefore the atmosphere of large industrial cities contains the highest proportions. Warnes's figure was determined in England in 1926 and corresponds closely with figures given by Merrill[49] in 1921 for several American cities. Motor traffic was very much lighter during those years than in American cities today, and it is probable therefore that the average atmosphere of cities of the United States contains a higher percentage of carbon dioxide than that given by Warnes.

Carbon dioxide gas is soluble in water to the extent of 1.796 per cent at 0°C., and such solutions are slow solvents of some rocks. Both calcium carbonate and magnesium carbonate are soluble in water saturated with CO_2, the former to the extent of 0.07 per cent, and the latter

[48] Warnes, Arthur R., Building Stones, Their Properties, Decay, and Preservation. Ernest Benn, Ltd., London, 1926, p. 172.

[49] Merrill, G. P., Rocks, Rock-Weathering, and Soils. John Wiley & Sons, Inc., New York, 1921, p. 157.

0.113 per cent at 0°C. With calcium carbonate the following reaction probably takes place: $CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$. Calcium bicarbonate or acid carbonate thus formed is relatively soluble in a carbon dioxide solution and consequently carried away. This slow dissolving action accounts for the prevalence of caves in limestone and dolomite rocks in regions where carbonated-water springs abound. It is extremely slow in sound, close-grained limestones and marbles and more rapid in those of open, porous texture.

The sand grains of some sandstones are cemented together with calcium carbonate, and such rocks are likewise disintegrated slowly by solution of the cement in carbonated waters. Carbon dioxide in solution reacts similarly on mortars and cements, particularly those containing free lime.

Sulphur dioxide (SO_2) is another important product of fuel combustion for many fuels contain sulphur compounds, especially pyrite (FeS_2), which oxidize and form fumes that are carried in the air. In the presence of moisture they form weak solutions of sulphuric acid (H_2SO_4), an agent much more active than H_2CO_3. When sulphuric acid solutions come in contact with limestones or marbles calcium sulphate is formed, according to the equation $CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2$. Under certain conditions the hydrous calcium sulphate, gypsum ($CaSO_4 2H_2O$), is formed. Calcium sulphate is slowly soluble in water; consequently, the surfaces of limestone or marble blocks are dissolved slowly if exposed for a long time to an acid-laden atmosphere. Sandstones with calcareous cement are acted upon in much the same way. Other acids, such as hydrochloric (HCl) and nitric (HNO_3) sometimes are present in the air in small quantities, and their solvent action is similar to that of sulphuric acid.

Certain chemical salts, such as ammonium chloride (NH_4Cl) and ammonium sulphate $(NH_4)_2SO_4$, are formed as products of fuel combustion, and small quantities are present in rain water. When they go into solution they are partly ionized or hydrolized and the acids thus formed react as described in a previous paragraph.

Carbon dioxide, acids, and dissolved salts react on hornblende, feldspar, and silica in such rocks as granites, sandstones, and slates but only to a slight extent, and much more slowly than on the carbonate rocks.

Alteration and Replacement of Minerals.—Alteration and secondary mineralization of rocks are broad subjects on which entire books have been written. The discussion herein is far from complete, being confined to the more outstanding agencies and processes that cause deterioration of building stones.

The changes that take place involve reactions between the constituents of stone and chemical agents derived from external sources, chiefly those carried by rain water. Hydration and oxidation are very common

processes, though many other chemical reactions occur. Hydration is common, because many secondary minerals or chemical products are hydrous sulphates, oxides, or silicates.

Oxidation alone may cause changes in color, with little or no detrimental effects. Thus, limestones containing ferrous carbonate may be bluish white when first quarried but may change rapidly to buff or yellow, chiefly through formation of limonite. Similarly, the sea green slates of Vermont change to a rusty brown on weathering, but this change in color is not regarded as an evidence of deterioration. Stonework, however, may be damaged through oxidation. Oxidation of sulphides to sulphates may result in swelling and consequent disruption. Oxidation of ferruginous carbonates of calcium and magnesium, or silicates of the mica, amphibole, and pyroxene groups may cause slow decomposition. Many stones are disfigured with rusty stains produced by oxidation of pyrite, marcasite, or other iron-bearing minerals. Oxidation of iron sulphides may form weak solutions of sulphuric acid that will react on certain constituents of stone.

The most damaging effects of the alteration and replacement of minerals are due to increase in molecular volume of the new minerals formed. Alteration of the original constituents of stone to new compounds occupying greater space creates internal pressure that results in disintegration. The most common substances that affect building stone adversely in this way are calcium and magnesium sulphates. When sulphuric acid comes in contact with a limestone either anhydrite ($CaSO_4$) or gypsum ($CaSO_4 2H_2O$) is formed. The increase in volume when calcium carbonate changes to anhydrite is in the ratio of 1 to 1.33; when it alters to gypsum the change in volume is as 1 to 2.15. If calcium sulphates thus formed crystallize within the stone the pressure of crystal growth has a disruptive effect when space is insufficient. Calcium sulphates are so slowly soluble in rain water that little relief from pressure is to be expected through solution of the products of chemical reaction.

Sulphuric acid acting upon magnesium carbonate forms epsom salts ($MgSO_4.7H_2O$), and the increase in volume is in the ratio of 1 to 5.3. This remarkable change would be exceedingly detrimental were it not for the easy solubility of magnesium sulphate in water. As it goes into solution readily much of it may be carried away before it can crystallize enough to cause serious disruption.

It is evident, therefore, that sulphuric acid in rain water may cause some deterioration in limestones, dolomites, marbles, and calcareous sandstones. Dense nonporous stones are affected but slightly, for reaction occurs too close to the surface to cause disintegration by crystal growth. Porous stone is damaged more seriously.

For reasons enumerated above slates having a considerable calcium carbonate content are not to be recommended as roofing materials for

buildings exposed to acid fumes, for example, those near fertilizer plants, because growth of calcium sulphate crystals between cleavage planes causes rapid deterioration. Calcium silicates react in the same way though much more slowly. The most enduring slates have a low calcium content. Most igneous rocks, such as granites and diorites, contain calcium and magnesium silicates and therefore are subject to the same reaction in a degree, but their insolubility or slow solubility in weak acids renders them more resistant than are the carbonate rocks. Nevertheless, granite columns and exterior walls have been damaged seriously by acid fumes.

Sodium chloride in sea spray may be deposited on stonework and its crystallization cause damage at or near the surface; however, it is to be regarded as a minor agent. Deterioration of monument bases and the lower courses of stone buildings may be caused by soluble salts in the soil carried upward by capillarity and drawn to the surface by evaporation. Crystallized gypsum on or near the stone surface has been traced to this source.

Detrimental effects resulting from crystallization of secondary compounds are most noticeable in stones that have pronounced cleavage, bedding, or foliation, because solutions usually enter cleavage planes with relative ease. High-grade slate is an exception to this rule, for while it is the most cleavable of all rocks it has a very low ratio of absorption. Mica schists, micaceous sandstones, and thin-bedded or laminated limestones may suffer in consequence of excessive absorption in the direction of cleavage.

The Department of Scientific and Industrial Research in England points out that decay results from close association of different types of stone. For example, rapid decay of sandstone has been attributed to the presence of calcium carbonate leached from adjacent limestone courses. By contact with sulphur dioxide the carbonate in the pores of the sandstone is changed to sulphate, and disintegration results from increased volume of the sulphate.

Although attention has been directed to the more active chemical agents of disintegration, certain slow weathering effects that have been in operation for countless ages must not be overlooked. The change of feldspar to kaolin, and of olivine to serpentine, as well as the alteration of pyroxenes and amphiboles to epidote, chlorite, and sericite are well-known processes of metamorphism. Such alterations in rock minerals are exceedingly slow and therefore of little interest to the stone producer or user in so far as deterioration after the erection of a building is concerned. They are mentioned here primarily as a warning that precaution should be exercised in the selection of stone. Buildings are exposed to the weather not more than a few hundred years at most, but outcropping ledges from which building stone may be obtained have been subject to

action of the weather for many thousands of years, and the effects may be in evidence several feet below the surface. On this account, surface rock usually is discarded as waste, for that which has already passed the earlier stages of decay can not withstand exposure as well as fresh rock quarried at depth. All competent quarry operators carefully avoid the use of stone that shows signs of weathering.

The petrographic microscope is of inestimable value in studying weathering of stone. In thin section under a microscope the beginning of kaolinization of feldspar is shown by a cloudiness, while fresh, unaltered spar is clear and colorless. Altered pyroxenes and amphiboles show stains of iron oxide with traces of sericite and even calcite. Stone that shows such definite evidences of alteration should not be used for structural or ornamental purposes.

Changes or Agencies Chiefly Physical. *Expansion and Contraction.*—With every change in temperature there is a slight change in volume of all rock minerals. According to data compiled by Warnes[50] the amount of expansion of a piece of granite 1 inch long for each degree Fahrenheit increase in temperature is from 0.000004 to 0.000008 inch; for sandstone, about 0.000009 inch; and for marble, about 0.000006 inch. Such amounts may seem too small to have any material effect, but when considered in terms of blocks several feet long, and under variations of many degrees in temperature, the change becomes more apparent. Thus, a block of sandstone 5 feet long will expand about one-twentieth inch in length if its temperature is raised from 0° to 100°F., and this amount may be sufficient to cause minute fractures in mortar joints. It is claimed that Bunker Hill monument, a hollow obelisk of granite 221 feet high and 30 feet square at the base, is measurably affected by expansion, for the top oscillates about one-half inch from morning to evening on a sunny day. During a visit some years ago to granite quarries on the coast of Maine the writer was informed that thin sheets of granite 50 or 60 feet long which are fast at the ends and so incapable of lateral expansion would arch upward at the center at least 2 inches on a cloudless day in midsummer. Fire setting has been used quite commonly as a substitute for explosives. Certain native races, for example those in some parts of India, build fires on granite surfaces and then throw water on the heated rock to cause spalling by sudden contraction of the surface; sheets thus obtained are used for structural purposes. The above illustrations indicate that expansion and contraction are important enough to warrant attention.

A few changes in temperature from hot to cold might have little or no effect on the quality of stone, but in climates subject to extreme diurnal and annual temperature changes, repeated expansion and contraction have a weakening effect. Stone is made up of countless crystals or grains

[50] Warnes, A. R., Work cited, p. 161.

closely packed together, and with increase in temperature each grain expands and crowds against those surrounding it. As the temperature falls contraction occurs, with consequent tendency to create infinitesimal seams which may be enlarged by infiltration of solutions and crystallization of salts. As rocks are poor conductors of heat, surface layers may be subject to much greater changes than the interior, and unequal strains thus created may intensify disruptive effects. Furthermore, the coefficient of expansion of crystals varies with direction; thus, a mineral grain may expand more in one direction than in another with consequent unequal strain.

Igneous rocks such as granites consist of a variety of minerals each of which has its own coefficient of expansion. Quartz, for example, expands about twice as much as orthoclase for the same change of temperature. Variations in temperature of rocks of heterogeneous composition are therefore more detrimental than similar changes in rocks consisting largely of one mineral. Granites and other igneous rocks usually suffer more from repeated excesses of heat and cold than do limestones, marbles, and sandstones.

Obviously, stone is more enduring in climates where diurnal and seasonal temperature changes are slight than in regions subject to excessive heat and cold. The equable, warm climate of Egypt has preserved its great obelisks and pyramids remarkably well. A uniformly cold climate is also favorable for rock preservation. While engaged in geological survey work on the Hudson Bay slope of northern Canada the writer was greatly impressed with the remarkable preservation of granite exposed for countless seasons since the glacial period; no doubt, this condition is due in some measure to the fact that changes of temperature are moderate. In Great Britain and in many eastern and central European countries climatic changes are not so excessive as in many parts of the United States, and buildings made of stone are relatively more enduring. In eastern and northern sections of the United States temperatures are subject to extreme changes that have relatively severe effects on exposed stonework.

The foregoing statements must not be interpreted to indicate that the life of stone buildings in many parts of the United States is short. Although expansion and contraction are factors that deserve careful attention, their effects on high-grade stone are extremely slow. Other types of building materials suffer as much and probably more than stone from severity of the climate.

Frost Action.—In the preceding discussion of the action of heat and cold no consideration was given to effects of low temperature on water contained within stone. In freezing, water expands about one tenth of its volume, and pressure exerted by this expanding force is so great that no stone is strong enough to withstand it. Consequently, if the pore

space is filled completely with water and the temperature falls below freezing some degree of disruption will occur. If the pores are only partly filled with water, leaving at least one eleventh of the space empty, necessary expansion may take place without fracturing. The more nearly complete the saturation the more serious the effect will be.

Most freshly quarried stones, especially limestones and sandstones, are almost if not entirely saturated with "quarry water," and the effects of frost on saturated blocks are very serious. Such stone is rarely quarried during the winter, for blocks must have at least several weeks to dry out before they are safe from frost action. However, it is important to note that when once the quarry sap has been dried out danger of serious damage by frost is past, even though soaking rains occur immediately before a heavy frost. Subsequent wetting evidently fails to bring about complete saturation, and enough pore space is left for normal ice expansion.

Detrimental effects of the action of frost have been exaggerated by some writers, probably because they judged effects observed on freshly quarried stone rather than on seasoned blocks. No doubt frost is a contributory cause of disintegration, but only in exceptional cases where saturation is nearly complete. Usually only one face of stone is exposed to the weather, and water which falls on the exposed face gradually passes inward to the dry interior. Rain seldom continues long enough for complete saturation, and frost rarely follows rain so closely that enough time has not elapsed for at least partial drying.

The most porous stone is not necessarily the one most seriously affected by frost because usually it gives up its water content readily, particularly if the openings are comparatively large. Stone with subcapillary pores, even though it has a low ratio of absorption, may be the most seriously damaged, because capillary action tends to keep the pores filled or nearly filled with water.

A uniformly cold winter climate is less detrimental in this respect than one characterized by repeated rain and frost for, just as many succeeding expansions and contractions have a weakening effect, so innumerable repetitions of minute frost fractures lead to deterioration.

The effects of frost do not depend solely on porosity. Incipient seams may fill with water, and frost will widen them. Laminated rocks may scale badly if water freezes in loose bedding planes. Complete destruction of stonework has resulted from placing blocks with their cleavage or bedding vertical, a position most favorable for spalling by frost if water is absorbed between the laminations. Limestones with shaly layers or any stones with seams that absorb water readily are not regarded favorably in regions where frost action is severe.

Abrasion.—Certain types of stonework, such as floor tile, walks, sills, and steps, are subjected to the wear of footsteps. In the concourses of

railroad stations, in corridors, lobbies, and on stairs of public buildings abrasion may be so intense that stone may be worn down an inch or more after many years of service. For such uses varieties that are known to be resistant to abrasive action are usually selected. Coarse-grained saccharoidal marbles, soft slates and limestones, and loosely cemented sandstones generally are avoided. Fine-grained dense marbles, silicated marbles, travertine, some varieties of slate, the harder types of soapstone, bluestone, indurated sandstone, and granite all have given excellent service for flooring and steps. Intelligent selection can be made best after abrasion tests are applied. Relative resistance to abrasion can be determined by bringing the various stones in contact with a grinding wheel or disk and weighing the cuttings obtained after a definite number of revolutions under uniform pressure. Those that give the smallest weight of cuttings are best adapted for uses where they are exposed to excessive wear.

Cutting or attrition of sand, sharp coal clinker, or other granular matter carried by wind is another form of abrasion that definitely reduces the surface of exterior building stone. The wearing and polishing effects of wind-blown sand are observable on many natural rock exposures. Projections are worn to rounded shape, soft spots and bands are cut into grooves and hollows, and surfaces become polished. In southwestern Minnesota the action of wind on exposures of quartzite has rounded and polished them until they have the appearance of lava or glass. Dust storms in the arid or semiarid sections of the Southwest have similar abrading effects. The battered face of the Sphinx and the fantastically carved natural monuments in the Garden of the Gods are classic examples of aeolian abrasion.

In towns and cities wind-borne particles consist principally of dust from streets or roads and soot or clinkers from stacks and chimneys. In country regions sand grains are carried from roads, fields, and hillsides. The abrasive action tends to be most severe in shore or coastal regions, where beach or dune sands are plentiful and where winds are more prevalent and attain higher velocity than at interior points.

Wind action on stone buildings is most intense close to the ground, particularly on corner blocks where air currents converge and wind pressure is high. Abrasion is most noticeable on walls facing the direction of prevailing winds. Stone carved in relief may be worn sufficiently to impair its effectiveness. Inscriptions on monuments in old cemeteries may become obliterated if they face the direction of prevailing winds. Pits and grooves may be formed where soft spots or bands occur. Deep pits may contain sand grains that are carried round and round by air currents wearing the holes larger in the same manner that pot holes are formed in stream beds. While wind action is a minor cause of injury to stonework, it is sufficiently important to merit care in the selection of

wear-resisting material for corners and surfaces exposed to unusual abrasion from that source.

Settlements.—Poor foundations or badly built walls may cause fractures in stone of the highest quality. Door and window caps or sills are commonly fractured, not as a result of seams or weaknesses in the stone, but because they were improperly placed or subjected to unequal strain or because foundations have settled causing a downward movement of certain parts of the wall. Many stone walls that should have existed in good condition for a long period are fractured beyond repair because of settling foundations. Unequal pressure, owing to faulty design, is a contributory cause.

Causes Both Chemical and Physical. *Plant Growth.*—Lichen and moss growths are common on monuments in many cemeteries and on old stone buildings, particularly on their shady sides. All lichens that grow on stone are not of the same character. Granites have types that prefer an acid environment, while limestones nurture entirely different varieties that subsist on more basic materials.

Lichen growth is not to be regarded as an evidence of stone decay, for these remarkable little plants have the power of disintegrating perfectly fresh, solid rock in obtaining food supplies. Nor do they depend on microcrevices for a foothold; botanists have found that they can penetrate the hardest rocks, even silica. However, the hyphae or rootlets of the fungus portion of lichens may more readily enter small fractures caused by surfacing machines or hand tools used in dressing stone.

The influence of plant growth on building stone is both mechanical and chemical. Root pressure gradually widens openings and causes small particles to fall away, and lichens secrete organic acids that have a mild corrosive effect, particularly on limestones, dolomites, and marbles. Lichens also retain moisture, soot, and grime on the surface of rock, thus aiding the action of solvents and possibly increasing the effects of frost. Ivy and creepers, although adding beauty to masonry structures, keep walls moist and secrete acids that have a mild solvent effect. After attaining a heavy growth, ivy inserts filaments between the stones, which by enlargement slowly impair the integrity of the wall. The claim has been made that bacteria are effective agents of stone decay, but they are probably of minor consequence.

Marine Borers.—Breakwaters, docks, harbor walls, and other subaqueous stone structures are damaged at times by certain rock-boring molluscs, such as pholas and lithophagus. They penetrate limestone, sandstone, or granite and may so impair walls that replacement becomes necessary. Boring is effected by chemical rather than by mechanical means.

Faults in Accessory Materials and Workmanship.—The quality and permanence of stonework depend to quite an extent on workmanship and

choice of supplementary materials. Defective roofs, gutters, and flashings or badly constructed window casements may permit water to soak into parapets or run behind stone facing blocks. Unsightly stains may be caused by the attachment of iron or steel bars to stone. The rusting of iron to iron oxide is accompanied by great expansion, and pressure exerted by a rusting iron bar closely fitted into a hole in stone may be enough to burst the block. Lead joints have been known to stain polished monumental marble.

Masonry mortars or cements are very important supplementary materials used with building stone. Open joints between blocks of stone caused by faulty mortar, or by use of too small an amount, are highly undesirable as they permit access of water or injurious solutions. According to Anderegg,[51] properties of mortars that demand special attention are, in order of their importance: Workability, bond strength, water-tightness, weather-resistance, flexibility, shrinkage, compressive strength, and freedom from efflorescence. Trainor[52] expresses the properties somewhat differently and lists them in order of their importance as follows: Plasticity, adhesion, volume changes after hardening, elasticity, resistance to frost, freedom from efflorescence, rate of hardening, absorption, and strength. Lime mortars, portland or natural cement mortars, and mortars containing both lime and cement are all used. Lime has properties that make it highly desirable, and cement has quite different qualities that are also advantageous in masonry mortars. These properties may be regarded as supplementary to each other, and for this reason many stonesetters prefer mortars containing both lime and cement. There are now on the market more than 40 masonry cements or mortars, ranging in composition from those with a major lime content to those in which the proportion of cement predominates. Mortar of any type should have a minimum content of soluble calcium or magnesium salts, as these may produce unsightly surface efflorescence. The nature and qualities of materials entering into a mortar are of minor importance, provided the desired properties of the finished product are attained. Much detailed information is to be found in the articles mentioned in the footnotes.

The importance of this subject has been duly recognized by the American Society for Testing Materials which in 1932 established a representative committee designated "C-12 on Mortars for Unit Masonry." The principal object of the committee as expressed at the time of its organization is "Research to promote knowledge of properties

[51] Anderegg, F. O., Analysis of Properties Desired in Masonry Cements. Rock Products, vol. 34, no. 25, 1931, pp. 40–42. Lime and Portland Cement for Masonry Mortars. Rock Products, vol. 35, no. 4, 1932, p. 46.

[52] Trainor, Leo S., Fundamental Properties of Mortar for Durable Unit Masonry. The Clay Worker, vol. 97, no. 5, May, 1932, pp. 250–253.

and tests of mortars for unit masonry, and development of methods of test and specifications for such mortars."

Weathering Effects on Stones of Various Kinds.—In summarizing weathering processes covered in preceding paragraphs some general conclusions may be reached regarding the relative effects of various agencies on different varieties of stone. Carbonate rocks (limestones, dolomites, and marbles) are altered chiefly by chemical action, and to a much smaller degree by physical agencies. Solution and slow disintegration on account of the expansion of alteration products are the chief causes of deterioration in rocks of this type. They are, however, little affected by expansion and contraction owing to temperature changes, and fine-grained impervious types suffer only to a small extent by frost action. Fine-grained limestones withstand the effects of fire remarkably well up to the point of calcination.

As compared with carbonates the effects of weathering agencies on granites, syenites, and similar igneous rocks are reversed in importance. Their disintegration is brought about chiefly by physical agencies, the most important of which are repeated expansion and contraction resulting from variations in temperature, although igneous rocks are generally as resistant as carbonate rocks to the effects of frost. Also, granites and similar rocks spall badly if the building in which they are used is burned.

Few general rules can be established for sandstones, because they are quite variable in character. Those with calcareous cement are affected chemically in much the same way as limestones and marbles. Porous sandstones are subject to disintegration by frost if they do not give up included water freely. Diurnal expansion and contraction have little effect. Firmly cemented siliceous sandstones probably are more resistant to weathering than other ordinary building stones.

Slates are affected very little by solution, although a high calcium content may lead to early disintegration if they are exposed to acid fumes or solutions. Expansion and contraction affect them slightly. As noted in the slate chapter, some high-grade American roofing slates show scarcely any weathering effects after exposure for 100 to 200 years.

Importance of Care in Selection of Stone.—As stated in a previous chapter, man can not change the quality of stone, but he has the power of selection. Ability to select wisely depends on fundamental knowledge of building stone, full comprehension of architectural demands, and an adequate understanding of the agencies already mentioned that tend to mar or weaken stone and to which the finished structure may be exposed. For instance, white marble or granite might not be suitable in an industrial city with smoke-laden atmosphere. Climatic conditions should also be considered. Porous shell limestone that will endure many years in the climate of Bermuda would disintegrate rapidly in the Middle Atlantic States. Consideration must also be given to the direction of prevailing

winds, which may carry polluted air from factories or chemical plants. Structures exposed to winds bearing corrosive gases should be made of stone that exhibits high resistance to chemical action.

PRESERVATION OF STONE

Preservatives.—A desire to maintain the integrity of ancient stone buildings showing evidences of deterioration has led to the use of preservatives with which to treat the surfaces to prevent further decay. Naturally, this work has been done more in Europe, where the buildings are older than in America. In England, especially, much study and experimentation have been devoted to the nature and effectiveness of various preservatives and to methods of application. Warnes[53] has presented an excellent review of the principal compounds employed and has pointed out their respective merits.

An ideal preservative must satisfy a number of exacting requirements. It is a solution applied to the surface of stone, the solid part of which—the actual preservative—remains as a coating upon evaporation of the solvent. The solution should penetrate some distance below the surface, and quite a number of applications may be necessary to accomplish this. It must be so noncorrosive that it will not affect the stone and sufficiently resistant to weathering action to retain its effects a long time. It should cause no noticeable staining or discoloration of the natural surface; most reagents used change the color to a slightly darker shade. It must prevent penetration of moisture and at the same time allow it to escape. The latter condition seems paradoxical and is contrary to the opinions of many that preservatives should seal the surface watertight. Such sealing is highly desirable as a preventive of decay from absorbed solutions and would be entirely feasible if stone were absolutely free of moisture. It is impossible, however, to attain perfect dryness in a wall already built and exposed to the weather, and if the surface of stone containing moisture is sealed the pressure of water vapor and the crystallization of salts beneath the coating will gradually result in deterioration. It seems desirable to so treat the surface that the pores are not completely closed; thus, escape of moisture is permitted and at the same time a surface is obtained which will prevent moisture from passing into the stone by capillary action. The latter condition may be attained by using materials having high water-repellent properties. Waterproofing materials should also be easy to apply and should be reasonably cheap.

Warnes has given careful consideration to preservative materials of many kinds, including linseed oil, china-wood oil, liquid paraffin, petroleum jelly, paraffin wax, mineral soaps, resins, glue, animal fats, cellulose compounds, and silicofluorides, and has come to the conclusion that paraffin wax dissolved in light petroleum distillate or coal-tar

[53] See bibliography at end of chapter.

naphtha is the best. The solution should contain no undissolved wax at a temperature as low as 45°F., but at the same time it should not be too dilute. Kessler,[54] of the United States Bureau of Standards, ran a series of tests of waterproofing materials covering two years. He found that heavy petroleum distillates, fatty oils, and insoluble soaps were the most effective materials; paraffin gave the highest waterproofing value and appeared to be the most durable. He also found that the effectiveness of waterproofing is influenced greatly by the character of pores; as stones with minute pores are more difficult to waterproof than those with large ones. As a result of experiments recently conducted at the University of Manchester, England, it has been found that a new preservative called "Cephasite" gives excellent results. The nature of the compound has not been revealed.

A lime wash prepared by mixing hydrated lime with water has been used for several centuries as a stone preservative. Usually some other ingredient, such as salt, tallow, milk, or casein, is added. A coloring agent may be used to simulate the appearance of the structure to which the wash is applied. Carbon dioxide in rain water gradually converts the lime into calcium carbonate. No doubt it is protective to some extent, but it has serious disadvantages. The finely divided lime is readily acted upon by acids, forming calcium sulphate which, as previously pointed out, is one of the chief agents of stone decay. When binding materials are added to the wash the surface may be completely sealed, which results in trouble from included moisture. Repeated applications may form a heavy coating that is liable to break off in cakes or patches. In any event, a lime wash is not an attractive finish for large and stately buildings, although it may be reasonably effective and not unsightly if applied every one or two years to cottages or farm buildings. It is very commonly applied to Bermuda coral limestone used both in walls of houses and as roofing slabs.

Waterproofing compounds are commonly applied to surfaces other than those exposed to prevent absorption and staining from brickwork, mortar, cement, structural steel, or other metal parts. As faces thus treated are all hidden, waterproofing compounds may be black or any other color.

Consolidating Processes.—If stone has already partly decayed a first step in its preservation is to consolidate the loosened particles. Silica applied as an alcoholic solution of silicon ester is, according to present knowledge, the material most satisfactory for this purpose. It decomposes in the presence of moisture, depositing silica and setting free ethyl alcohol. The precipitated silica acts as cementing material for loosened grains, and covers all particles with a thin film. The alcohol evaporates and has no injurious effects. For best results application

[54] See bibliography at end of chapter.

must be made by an experienced workman. Other consolidating materials, such as sodium silicate (alone or with acids or calcium chloride), hydrofluosilicic acid, silicofluorides, barium hydrate, resin, metallic salts of fatty acids, and solutions of shellac either cause efflorescence or rock corrosion or are detrimental in other respects.

Normally, the consolidating process is followed by one of the waterproofing processes previously mentioned. When a preservative is applied before decay begins the consolidating process may be omitted.

General Considerations.—As may be inferred from the preceding paragraphs, weatherproofing is difficult both in selection of materials and in technique of application. It may become a necessary step for the preservation of historic edifices, but probably never will be found satisfactory for general use. The difficulties and limitations of artificial preservation emphasize the inestimable importance of selecting for exterior use in monumental buildings the very highest grades of weather-resisting stone. The fact that fair success has been attained in the application of preservatives is no excuse for using stone of inferior quality for noble structures.

CLEANING STONE

Necessity for Cleaning Process.—The surface of stonework gradually becomes soiled from external causes. Grime may accumulate rapidly in smoky industrial cities, although stone may remain comparatively clean for many years in the open country or in towns and cities where little soft coal is used. The lower courses of stone buildings are exposed to many agencies which soil and discolor. Tombstones and monuments are commonly coated with lichens or with wind-blown soil or soot. Their surfaces may also be stained with solutions carried upward by capillarity from the soil or from cementing materials at the base. Many building stones exhibit characteristic individuality, and their distinguishing features are lost when the surface becomes coated with foreign material. To renew the surface that it may in some measure present its original appearance requires some process of cleaning, which is also a necessary step preparatory to any process of preservation.

Polished stone accumulates dirt less readily than unpolished surfaces and is also very easily cleaned. Although polished surfaces are expensive, they are chosen for the base courses of many large buildings because of their attractiveness and cleanliness.

Although innumerable large stone buildings sooner or later require some cleaning process, at times cleaning is detrimental rather than beneficial.. The mellowing influence of time is a beautifier of architectural stonework. Old buildings may be neither stained nor disfigured, their color tones being merely softened and harmonized with the surroundings. Many Americans sadly lack appreciation of an atmosphere of antiquity

and seek newness at the expense of that attractiveness which weather-ageing alone can supply.

Cleaning Methods.—Methods of cleaning stonework may be classified in general as follows:

- Dry processes
  - Working to a new face
  - Sand blasting
  - Wire brushing
  - Rubbing with Carborundum block or grit stones
  - Heating with blow torch
- Wet processes
  - Scrubbing with water only
  - Scrubbing with various solutions and abrasives
  - Applying acids
  - Steam cleaning

Dry Processes. WORKING TO A NEW FACE.—Dressing a face with stone masons' tools presents a new surface, but it demands skilled labor and is therefore very expensive and usually unnecessary. The original surface of a stone block, case-hardened to some extent by crystallization of salts contained in quarry sap, is harder than any subsequent surface, and as redressing removes it the new surface is less durable than the original. As reworking is both detrimental and expensive it is rarely employed.

SAND BLASTING.—The sand-blast method is used widely for renovating soiled stone-work but is entirely too severe in its effects to be recommended as a cleansing agent. A sand blast removes grime by carrying away the stone particles to which soot or soil adheres. It has the same disadvantage as working down the surface with tools, namely, removal of the original hard surface. Sand blasting also rounds off sharp edges and disfigures fine carving.

WIRE BRUSHING.—A wire brush sometimes is used to clean stone surfaces but is unsatisfactory, as it removes only loose soot and grime or loosened particles of decayed stone. The softer stones may be brushed to a fairly clean surface, but the harder varieties, with closely adhering dirt or stains, cannot be cleaned effectively by this method. Moreover, awkward corners and angles around cornices, moldings, or carvings cannot be reached easily with a brush. Wire brushing may also cause stains from the rusting of specks of iron left on the stone surface.

RUBBING WITH CARBORUNDUM BLOCK OR GRIT STONE.—Rubbing down with dry abrasive stones is so ineffective that it is rarely used. It presents difficulties similar to those of wire brushing, namely, inability to obtain a clean surface and to work in narrow spaces and corners.

HEATING WITH BLOW TORCH.—Heating a stone surface with a blow torch and brushing away loosened fragments of stone is about the most abusive method of cleaning that could be devised. Excessive heat

applied unevenly scales and disintegrates the surface, leaving it in bad condition for resisting weathering effects.

Wet Processes. SCRUBBING WITH WATER ONLY.—A scrubbing brush and hot or cold water are used frequently for cleaning stone. Although superficial dirt may be removed thus the process has little or no effect on closely adhering soot or grime caked on the surface. It also fails to remove foreign matter which enters the pores of stone.

SCRUBBING WITH VARIOUS SOLUTIONS AND ABRASIVES.—Pumice, diatomite, sand, stone dust, or other abrasives are used with water for scrubbing surfaces of stone, and while more effective than pure water they are far from satisfactory. Various reagents dissolved in water are also used. Some are fairly effective, but quite a few are injurious if not used carefully. Some of the more common reagents that demand judicious use are discussed briefly.

CAUSTIC SODA.—Caustic soda ($NaOH$) dissolved in water is commonly used alone or in conjunction with sand or other abrasive for scrubbing stone surfaces. Strong caustic soda may have corrosive or disintegrating effects, particularly on carbonate rocks. Carbon dioxide in the atmosphere changes it to soda carbonate, and sulphur dioxide may alter it to sodium sulphate. Both changes involve increased molecular volumes, and if such reactions take place in porous stone that has absorbed the solutions, surface disintegration may result. If employed at all this reagent should be used with great care.

SOAP SOLUTIONS.—Soap, with or without dissolved salts or abrasives, is widely used. Soap solutions are subject to slight hydrolization into acid soap and free alkali, usually caustic soda, the effect of which has already been mentioned. If strong soap solutions are used they should be thoroughly washed from the surface.

ACIDS.—Hydrochloric and hydrofluoric acids sometimes are employed, but their use should be discouraged. The effects of acids on stonework have been covered in an earlier part of this chapter dealing with deterioration. Although they may be effective as cleansing agents they corrode and discolor the stone. Discoloration is due largely to chemical reactions with iron-bearing constituents of the stone. Acetic acid is milder in its action.

Special Cleaning Methods.—Much experimentation and research have been conducted on cleaning processes, and as a result stône associations, Government bureaus, or private companies have worked out formulas or have prepared special compounds which they recommend as effective and harmless. Several proprietary compounds are on the market and are advertised in stone-trade journals.

Methods of Cleaning Limestone.—The following method has been recommended for cleaning limestone: The equipment required is a steam boiler capable of producing steam at 150 pounds pressure, and two sets

of hose, one for steam and one for water. Cold water and steam at high pressure are mixed in a special nozzle, and the result is a spray of very hot water impinging on the stonework at high velocity. This dissolves and carries away the soot, grease, and dirt. It is claimed that hot water is more effective than steam, but this is doubtful. Where this method is not practical the surface of the stone may be scrubbed with an ordinary fiber brush and any white soap powder dissolved in soft water.

For oil, rust, smoke, and other stains not over a year old and not dried deeply into limestone the following method was recommended some years ago by the Indiana Limestone Quarryman's Association; Wash the stone with a solution of 2 pounds of oxalic acid in 1 gallon of water, allowing time for it to soak in; then spread over the face of the stone to a depth of one sixteenth inch a paste made by mixing 3 pounds of chloride of lime with 1 gallon of hot water; leave the paste in contact with the stone for 24 hours; if upon its removal the stains have not disappeared, repeat application of paste several times if necessary.

For removal of cement stains a mixture of chloride of lime and potash in equal quantities is recommended. Enough plaster of paris should be added to make a putty, which is applied to the stone and allowed to stand for a week or longer. A layer one half inch thick of hot-lime putty is also recommended. It should be left on the surface of the stone for several days.

Methods of Cleaning Granite.—The following methods of cleaning granite surfaces have been worked out by the United States Bureau of Standards: Ordinary accumulations of dirt may be removed by scrubbing with a stiff fiber brush and a grit cleaning powder and warm water. The stone surface should first be soaked thoroughly with clean warm water, the brush dipped in water and then in the dry powder, and applied to the surface with vigorous scrubbing. Suitable powders may be purchased under various trade names such as "Old Dutch Cleanser," "Marblica," or "Wyandotte Detergent."

Lichens or moss growths on granite may be removed with a caustic solution of 3 or 4 tablespoonfuls of ordinary lye in 1 gallon of water applied with a stiff fiber brush. The treatment should be preceded and followed by thorough washing of the surface with clean water.

Stubborn cases of soiled granite usually may be cleaned with ammonium fluoride or ammonium bifluoride solutions made by dissolving about one half pound of the crystals in 1 gallon of warm water. Such solutions etch granite to some extent and hence should not be used on polished surfaces. They should be applied after a preliminary wash with clear water, left on the surfaces only long enough to give desired results, and then thoroughly rinsed off.

Stains that have penetrated the surface and which cannot be removed by the last-named process require special treatment. Generally the

method of treating stains on interior marble, which is described in a later part of this chapter, may be applied with equal success to granite.

Steam Cleaning.—A steam jet for cleaning stone has been used generally during recent years. Steam is generated in a portable boiler placed near the building to be cleaned and is carried to any desired point through flexible metallic hose. A boiler pressure of 40 to 60 pounds a square inch is maintained, but the effective pressure of the steam as it reaches the stone surface is very much less. Warnes, in the book previously cited, estimates it at 1½ to 2 pounds a square inch, a force too weak to wear the stone, though it will carry away loose particles. Cleaning with steam is the most satisfactory method yet devised. Not only is it effective in removing dirt, but a steam jet is easy to direct into all corners, into the intricacies of carvings, or into narrow places that are difficult to clean by scrubbing processes. Furthermore, if properly conducted the process is not injurious to stone. Some complaint has arisen, because in an effort to speed up the cleansing process strong reagents, such as caustic soda or acids, are used in conjunction with steam, but such unwise accessory treatment should in no sense condemn steam cleaning.

While steam cleaning is effective for ordinary dirt it will not always bring back the original color to the surface, because iron stains resulting at times from alteration of iron-bearing minerals in the stone may be deep-seated and difficult to remove. For the more tenacious discolorations scrubbing with chemicals before steam cleaning may be necessary, but care should be exercised in choice of reagents.

Maintenance of Interior Marble.—Stone used for interior structural or decorative purposes, while not exposed to the weather, is subjected to many soiling and staining agencies. Floors, particularly, require frequent cleaning. Iron rust, tobacco, ink, oil, and various other stains may require special treatment. Kessler[55] has made a very exhaustive study of the maintenance of interior marble, and his conclusions are worthy of brief review. Many of the methods proposed may be applied with equal success to the treatment of stains and discolorations on other kinds of stone.

Kessler found that commercial cleaning preparations fall into two classes—a scouring type containing abrasive powder, usually volcanic ash, and a nonscouring type consisting of soap or alkali salts. Scouring powders are not appreciably injurious to floors or other unpolished marble but should not be used on polished work. The lower part of polished baseboards is often injured by contact of mops and brushes used in scouring floors. Soapstone and talc grits will not injure polished marble. A preparation consisting of 90 per cent soapstone and 10 per cent soap powder is effective and satisfactory for cleaning either marble floors or polished surfaces.

[55] See bibliography at end of chapter.

Injury to marble work may result from frequent use of such detergents as sodium carbonate, sodium bicarbonate, or trisodium phosphate used in nonscouring compounds. The effect is physical, owing to crystallization of salts in the rock pores. Marble work may be safely cleaned by such compounds if the surface is first rinsed with clear water. Although soap is sometimes objectionable it gives satisfactory service if used with soft water. Ammonia water, acids, and preparations containing coloring ingredients should be avoided.

Interior marble sometimes is stained when in contact with damp walls, because moisture dissolves salts from masonry and slowly deposits them in the stone. Marble slabs may be protected from such effects by waterproofing the back of the slab before it is installed. Molten paraffin driven into the pores by heat is an effective sealing agent.

Treatment of Stains.—Stains that have penetrated marble usually require poultice treatment. No one method is applicable to all kinds; most of them require special methods. Kessler's recommendations for the more common types of stains are given briefly, as they apply also in a general way to other types of rock. Details of treatment may be found in his Technologic Paper 350, mentioned in the bibliography at the end of this chapter.

For removing mild iron stains dissolve 1 part of sodium citrate in 6 parts water, add an equal volume of glycerin, mix thoroughly, and add whiting to form a paste. Apply it to the stained surface and leave for several days, repeating the treatment if necessary. For deep iron stains sodium hydrosulphite ($Na_2S_2O_4$) may be used; the surface should first be soaked with a solution of sodium citrate.

Green or brown stains from copper or bronze may be removed with a poultice made by mixing in dry form 1 part of ammonium chloride (sal ammoniac) with 4 parts of powdered talc and adding ammonia water to form a paste. A solution of 8 ounces potassium cyanide in 1 gallon of water is also recommended, but this is a very poisonous solution that must be handled with great care.

Ordinary ink stains may be treated with a strong solution of sodium perborate dissolved in hot water, to which is added enough whiting to make a thick paste. It is applied in a layer one-fourth inch thick and left until dry.

Tobacco stains usually can be removed with a paste made by mixing any of the ordinary grit scrubbing powders with hot water.

For oil stains cut a piece of white canton flannel somewhat larger than the stain and saturate it with equal parts of acetone and amyl acetate. Place it over the stain and cover with a piece of glass or a slab of marble. The cloth should be resaturated several times. For surface oil stains that have not penetrated deeply into the stone nor oxidized, benzol or gasoline may be mixed with hydrated lime, marble dust, or whiting to make a paste which is plastered over the stain.

Linseed-oil stains from putty are difficult to remove, and several methods are recommended. Repeated applications of hydrogen peroxide may be effective, or a special poultice may be used. It consists of 1 part of trisodium phosphate, 1 part of sodium perborate, and 3 parts of powdered talc made into a paste by adding a strong soap solution. Repeated applications of the paste may be necessary. To prevent occurrence of linseed-oil stains substitution of grafting wax for putty is recommended where plastic material is required to fill around pipes or for other applications in contact with marble.

General service stains embrace dingy or yellowish effects due for the most part to improper or insufficient cleaning. They may usually be removed by scrubbing with javelle water or by poulticing with commercial grit scrubbing powders.

The following method of removing fire stains from stone was given by an English writer in 1931: To 1 gallon of soft soap add 2 pounds of finely powdered pumice and 1 pint of liquid ammonia. After mixing thoroughly apply with a fiber brush. Allow to remain on the stone 30 or 40 minutes and then rub the surface briskly with a sponge or scrubbing brush dipped occasionally in clean warm water.

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PART III

CRUSHED AND BROKEN STONE

CHAPTER XVI

GENERAL FEATURES OF THE CRUSHED-STONE INDUSTRIES

History.—Dimension stone has been in use for many centuries, but employing stone in fragmentary form, except in very small quantities, is a comparatively recent development. The convict chain gang, breaking rocks with hand sledges to improve the surface of highways, was a forerunner of the extensive crushed-stone industry, which grew with accelerated speed after the invention of portland cement. The manufacture of cement has attained enormous proportions, with a production of about 175,000,000 barrels a year. Nearly all of it is used in concrete, which requires gravel, slag, or crushed stone as aggregate. Furthermore, the manufacture of cement itself consumes a very large tonnage of limestone. Within the past 50 years the production of crushed stone grew from small, insignificant stature to a volume of approximately 188,000,000 tons a year in 1929. The quarrying and preparation of this vast tonnage employ several thousand men and require an enormous investment in equipment, because the processes are largely mechanical.

Types and Quantities Employed.—The chief varieties of rock used as crushed stone are limestone (including marble), sandstone (including quartzite), granite, basalt and related rock (trap), and various other rocks generally grouped as miscellaneous. The tonnage of these various types produced in crushed and broken form is shown in the following table compiled from United States Bureau of Mines figures:

CRUSHED AND BROKEN STONE PRODUCED IN THE UNITED STATES, 1929–1930 AND 1936–1937, IN SHORT TONS, BY VARIETIES

Kind	1929	1930	1936	1937
Limestone (including marble)	151,365,350	134,621,120	123,148,990	131,772,990
Basalt (trap rock)	14,820,140	14,492,800	13,977,030	13,556,360
Granite	9,115,700	8,717,170	14,775,300	8,514,500
Sandstone (including quartzite)	5,134,600	3,950,240	6,091,840	4,841,030
Miscellaneous	8,179,870	8,525,690	7,764,740	10,374,130
Total	188,615,660	170,307,020	165,757,900	169,059,010

The quantities of limestone given in this table include that ordinarily designated "crushed stone," together with that consumed in the manufacture of cement and lime and for miscellaneous uses.

The chart (figure 66) shows graphically the rapid and enormous growth of the crushed-stone industry from 1907 to 1932. However,

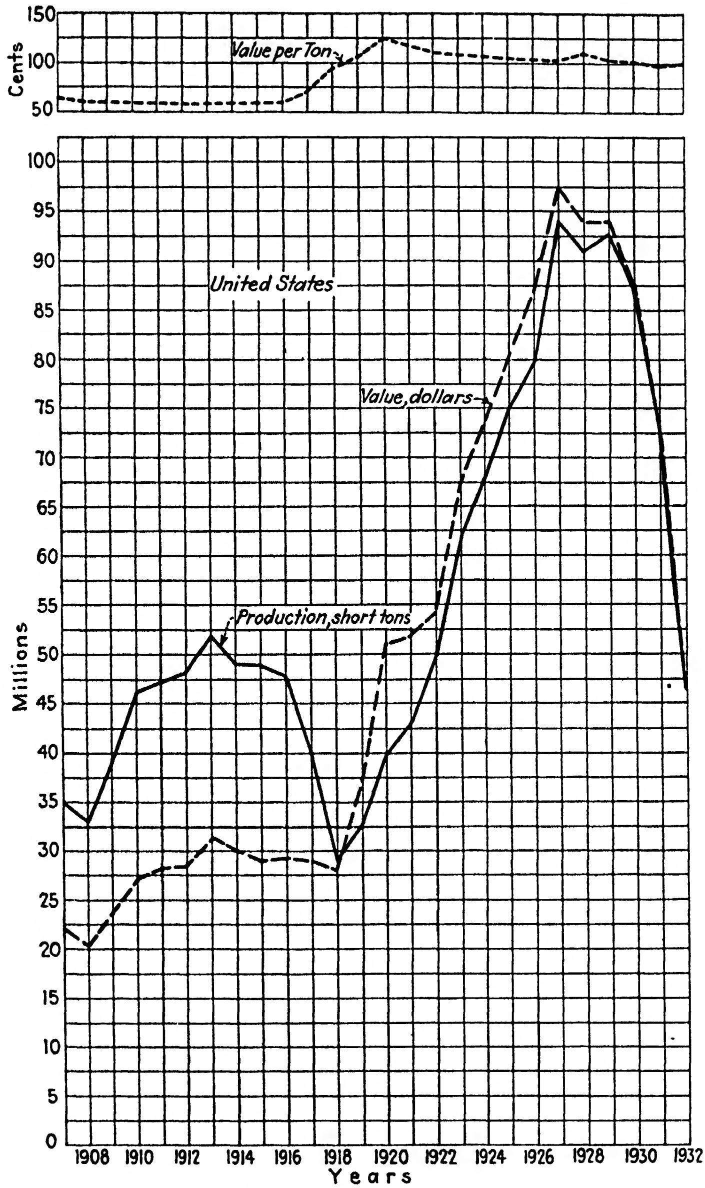

FIG. 66.—Quantity and value of crushed stone sold in the United States, 1907–1932.

this graph does not correspond with figures of production as given in the preceding table, because it is based on production of concrete aggregate, road stone, and railroad ballast only. As may be observed

in the chart, the production curve for the entire country rises to a sharp peak in 1913, recedes slightly during the early years of the World War, and then drops precipitously in 1917 and 1918. After 1918 production increased steadily each year at a fairly uniform rate until 1927, the peak being almost double that of 1913, the high year up to 1918. The extensive road-building programs in many States probably constitute the largest single factor influencing this sharp increase. A second pronounced drop in the curve began in 1928 preceding by a year the general business depression and market breaks that began late in 1929.

Crushed Stone and Dimension Stone Contrasted.—The dimension-stone and crushed-stone industries have little in common, except that both employ native rock as raw material. For quarrying dimension stone explosives are used very sparingly, as the integrity of blocks must be maintained. Cuts are made with channeling machines or wire saws, or rock masses are separated by wedging, whereas in quarrying crushed stone heavy charges of dynamite are used for fragmentation. Similarly, in all subsequent steps of preparation for market methods and equipment are sharply contrasted. The producer of dimension stone uses saws, planers, Carborundum machines, rubbing beds, and polishers; the producer of crushed stone employs churn drills, power shovels, crushers, screens, elevators, and belt conveyors. Dimension stone is sold chiefly by the cubic foot, and much of it commands a price high enough to give it a nationwide market. Crushed stone is sold by the ton and is so low-priced that it will not bear heavy transportation expense. As raw materials for crushing are available in many places, quarries are numerous and are scattered throughout the country in thousands of communities, whereas the dimension-stone industries are centralized in a much smaller number of localities.

Uses of Crushed Stone.—The chief uses of crushed stone are for road building, as concrete aggregate, and as railroad ballast. In highway construction it is used as concrete aggregate, for road base, in waterbound macadam, and in various other ways. Concrete, now used extensively in all building construction, consumes large quantities of crushed stone or similar aggregate. Millions of tons are used to ballast railway lines throughout the country. In one or more of these three major applications crushed stone finds a place in the experience of virtually every citizen. Numerous other uses are discussed in following chapters.

Competition.—Stone suitable for crushing is obtainable in many places; in most regions it is practically impossible for an operator to monopolize available deposits. Furthermore, he must face competition from natural gravel, which is sold in immense quantities, and, in territory near smelters, from crushed and granulated slag. Success in meeting competition from other stone producers depends somewhat on relative conditions, such as depth of overburden or ease of transportation. The

operator who controls the most favorably situated part of a deposit enjoys an economic advantage. Modern trends involve more complete mechanization of plants and the consolidation of small organizations into fewer large ones. The former reduces production costs, and the latter absorbs competitors and reduces administration expense through more centralized control. With ever-increasing rigidity of specifications the quality of the product is also an important factor in competition, because a superior product may compete successfully with a lower-priced, inferior commodity.

Markets. *Local Markets.*—Crushed stone commands a low price; therefore, as haulage charges are relatively high, profitable operation depends largely on the extent of local markets. The producer of crushed-stone is most interested in steady market requirements to supply every-day needs of builders, contractors, State highway departments, and other users. As such requirements have a definite relation to population, an increasing demand may be expected in growing communities. Large crushing plants supplying wide markets usually suffer less from variation in local demands than smaller plants with limited market areas. A new highway, dam, or bridge may require large quantities of crushed stone for a time, but the demand is reduced greatly when the project is completed. The wise producer gages his plant capacity by the normal demand but is prepared to profit by any extraordinary market opportunities.

The demand for crushed stone varies greatly in different communities, even though they are similar in population and in per capita wealth. Demand is influenced by prevailing types of architecture and by availability and cost of materials, such as sand and cement used with crushed stone, and by competition of concrete with brick, stone, or other products.

Distant Markets.—Although crushed stone is a low-priced product with a relatively limited market range, during recent years the market area of many plants has been extended greatly. Production costs have been reduced by the use of more efficient equipment and methods and by consolidation into larger units. Transportation facilities have been improved also. Year by year hard-surfaced highways are extended, and trucks hauling heavy loads at 35 to 50 miles an hour are multiplying. Increasing use of water transportation, notably on the Great Lakes, is an important trend. Plants with large-tonnage production, efficient equipment, economical management, and low-cost transportation may ship their products long distances and compete successfully with local stone in far-distant markets.

Transportation.—The haulage charge usually is a large part of the delivered price of crushed stone. Producers strive to maintain low freight rates, because even small increases are serious handicaps in a competitive

field and tend to reduce market areas. Automobile trucks, water carriers, and railroads are the three principal means of transportation. The first and second have made notable progress during recent years, consequently rail carriers have suffered some recession in their share of a rapidly increasing business.

Prices.—Market prices for crushed stone differ materially from metal prices. Copper, for example, is quoted at a certain price per pound which is virtually constant throughout the entire country and even in foreign markets. The price per pound is relatively so high that the cost of transportation is too small to influence it appreciably. On the other hand, transportation expense influences the price of crushed stone greatly. Prices are therefore subject to local conditions of production cost, and competition. Usually the market columns contain about 50 quotations representing the chief market centers. Prices may vary widely even within restricted areas; therefore, the determination of selling prices is an individual problem for each producer. As may be noted from the curve (fig. 66), the average price of crushed stone at the quarry is generally a little more than $1 a ton.

Royalties.—Many crushed-stone producers operate in deposits they do not own. In such instances it is customary to pay the owner of the property a royalty of so much per ton of crushed stone sold. Data on which royalties are based have been discussed in chapter V. Royalties for crushed stone are 1 to 10 cents a ton depending on local conditions. The lower figures usually prevail where production is large, but other factors, such as sales value per ton or production cost, may influence the amount.

Capital Required.—A prospective operator desires to know how much capital he must have to establish a crushed-stone industry. Investment of capital is subject to considerable variation because of the number and variety of elements that enter into it. Just as the operating cost in no two quarries is the same, so the capital required to establish two equally efficient crushing plants may vary widely. It is interesting, however, to know even approximately the average investment for a stone quarry and crushing plant.

The most reasonable basis for expressing investment is the capital required per ton of annual production. Thus, if the plant costs $1,000,000 and the production is 1,000,000 tons a year, the investment is $1 an annual ton. Certain variables enter into the problem at this point, for annual production may refer to actual output or to plant capacity, and the production capacity of a plant depends on efficiency of management as well as on equipment. Capital investment, expressed in terms of actual tons produced over a series of years, probably is of more value to the industry than a figure based on rated plant capacity.

A detailed study of 64 crushed-stone plants in the United States shows, according to a recent report,[56] an average capital investment of $1.25 an annual ton of average production over a two-year period. This figure is based on depleted values representing actual replacement values of the properties. Therefore, a prospective producer who is just beginning operation, putting up new buildings, and buying new equipment must estimate his initial investment at a somewhat higher rate than the figures given above. Land and mineral constitute about 15 per cent of the total capital requirement, plant and equipment about 85 per cent.

[56] Bowles, Oliver, Economics of Crushed-stone Production. Economic Paper 12, U. S. Bur. of Mines, 1931, p. 53.

CHAPTER XVII

CRUSHED AND BROKEN LIMESTONE

TYPES OF STONE INCLUDED

For many uses the chemical composition of crushed stone has little significance. On this account the general term "limestone," as used in the crushed-stone industry, includes both pure and impure limestone, high-calcium limestone, magnesian limestone, dolomite, and crystalline forms that usually are classed as marbles. However a comparatively small amount of crushed marble obtained as a by-product of the block-marble industry is not included in the production figures given in a following paragraph.

EXTENT OF INDUSTRY

Limestone is the most widely used of all rocks and is essential in a greater number of industries than any other metallic or nonmetallic mineral substances. It might be claimed that iron and steel are employed more widely, but those industries as constituted at present could not exist without large quantities of limestone; thus, it is indirectly essential to all the uses of iron and steel. Other rocks, such as granite, trap, and sandstone, are also used as crushed stone, but they form a smaller part of the industry; limestone accounted for more than 80 per cent of the total amount in 1929. The quantity produced from 1926 to 1937 is shown in the following table:

CRUSHED AND BROKEN LIMESTONE* SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 1926–1937

Year	Quantity, short tons	Year	Quantity, short tons
1926	141,321,640	1932	69,672,740
1927	151,163,700	1933	65,938,430
1928	149,025,390	1934	81,446,000
1929	151,135,720	1935	82,688,160
1930	134,425,430	1936	123,081,030
1931	102,789,680	1937	131,660,690

* Includes stone used for cement and lime manufacture.

USES OF CRUSHED AND BROKEN LIMESTONE

The uses of limestone are more numerous and diversified than those of other stones, because it has physical properties that adapt it to practically all the uses for which any form of crushed stone may be employed; and in addition, it has active chemical properties that make it not only useful

but absolutely essential to a great many industries. The quantity of crushed or broken limestone applied to various uses is indicated in the following table for a typical year, adapted from United States Bureau of Mines figures.

CRUSHED AND BROKEN LIMESTONE SOLD OR USED IN THE UNITED STATES IN 1930, BY USES

Uses	Short tons
Riprap	2,918,110
Crushed stone	56,775,060
Fluxing stone	17,021,350
Sugar factories	414,340
Glass factories	224,180
Paper mills	248,790
Agriculture	2,542,100
Alkali works	4,436,160
Asphalt filler	430,290
Calcium carbide works	364,750
Carbonic acid works	2,290
Coal-mine dusting	47,750
Fertilizer filler	12,240
Filter beds	30,860
Magnesia works (dolomite)	111,740
Mineral food	30,350
Mineral (rock) wool	64,850
Poultry grit	45,920
Refractory stone (dolomite)	453,350
Road base	139,030
Roofing gravel	1,740
Stucco, terrazzo, and artificial stone	59,570
Whiting substitute	119,350
Portland cement (including "cement rock")	40,500,000
Natural cement ("cement rock")	341,000
Lime	6,780,000
Other uses*	310,260
	134,425,430

* Includes stone for ammonia, baking powder, lime burners, nitrates, phosphates, powder, purification of copper, reduction of aluminum ore, soap, sulphuric acid, and uses not specified.

For concrete aggregate, road stone, and certain other applications such physical properties as hardness, strength, and porosity have primary importance. For other uses, such as lime manufacture and furnace flux, chemical composition is much more important than physical character. The uses described in following pages are grouped in these two major classes.

Uses for Which Physical Properties Are Most Important. *Concrete Aggregate.*—Within the past twenty-five years concrete has become a construction material comparable in importance with structural steel. The cement output in the United States has reached the enormous volume

of about 175,000,000 barrels annually; and nearly all of it is used in concrete, principally for highway construction and in the building trades. The vast tonnage of aggregate required consists chiefly of limestone, although other kinds of crushed stone as well as gravel and slag are used quite extensively. For such use limestone should be strong, sound (free from incipient cracks or seams), and of low porosity. Much work has been done in the development of tests by means of which the quality of aggregate may be judged. A complete list of tests and specifications has recently been published.[57] Requirements of users differ widely, but generally aggregate should consist of clean, hard, strong, durable, uncoated fragments free from injurious amounts of soft, friable, thin, elongated or laminated pieces.

Alkalies and organic matter usually are regarded as undesirable. Soluble sulphides are objectionable, as they oxidize and give sulphuric acid, which attacks any calcareous aggregate or lime present in the cement, forming gypsum. Gypsum expands greatly during crystallization, thus disrupting the concrete. The chief qualities to be determined are strength, soundness, and resistance to abrasion, although porosity, hardness, and other properties may be considered. Standard tests include the Deval abrasion test, the Dorry hardness test, the Page impact test, and the ordinary methods of crushing-strength tests. Soundness is important because disintegration of some concretes has been traced to incipient seams or to other physical defects in the aggregate. Various tests have been devised to determine the soundness of coarse aggregates. The more important of them are: (1) freezing and thawing tests; (2) the sodium sulphate test; (3) the sodium chloride test; and (4) the alkali test. Each method involves the freezing or crystallization of a substance in the pores or cracks, resulting in heavy interior strain.

Requirements may vary considerably, depending on whether the stone is to be used for concrete aggregate, with bituminous material, or in some other way. State highway officials are recognizing the need for more uniform specifications, and this need has found expression recently in a set of tentative standards[58] covering stone to be used in the construction of both macadam and concrete highways.

Much study is being devoted to the proper sizing of aggregates and the proportioning of the various sizes necessary for maximum strength and durability with a minimum of cement. The present tendency is toward a combination of sizes that will give the lowest percentage of voids; in other words, the aggregate mixture should approach a condition of maxi-

[57] Ingels, C. W., National Directory of Commodity Specifications. U. S. Bur. of Standards Misc. Pub. 130, 1932, pp. 169–174.

[58] Tentative Standard Specifications for Highway Materials of the American Association of State Highway Officials. Washington, 1929, 56 pp. (see also revision of 1931).

mum density. This condition is best attained when two diverse sizes are used.

Road Stone.—Various sizes of stone are used for bituminous and macadam roads. Material under ¼ inch, classed as fine screenings, is used principally for waterbound macadam. Coarser screenings up to ½ inch are employed as fine aggregate for bituminous concrete. Sizes between ¼ inch and ¾ inch classed as dustless screenings or chips are utilized for surface treatment of bituminous roads. Sizes between ¾ inch and 1½ inch are used as coarse chips for bituminous macadam. Sizes ranging from 1¼ to 2½ inches are suitable for the wearing course of waterbound or bituminous macadam. Fragments between 2½ and 3½ inches are used for base courses of highways.

The requisite qualities of road stone are similar to those of aggregate, except that resistance to abrasion has first importance, for the stone should be tough and hard enough to withstand the pounding and grinding of traffic. For this reason, road stone may be subjected to an impact test to determine its wearing qualities. Thousands of tests have been made by the Department of Agriculture, Washington, D. C., to determine the physical properties of road stone, and a tabulation of results has been published.[59]

Road stone should break into sharply angular, chunky fragments. Such fragments, if properly graded by size, will compact solidly into the surface of the road and on account of the strong interlocking of angular pieces will offer maximum resistance to disruption by traffic. Soft stone breaks up rapidly under traffic; and laminated stone, even if fairly hard, will break into flat or elongated pieces which will not compact solidly. Rough-faced fragments bind and wear better than those with smooth surfaces. A low ratio of absorption is desirable; otherwise, water may penetrate and soften the structure of the road. Various standard methods of tests, sampling, and mechanical analysis are given in American Society for Testing Materials Standards, part 2, 1927.

Railroad Ballast.—Many thousand tons of limestone are used by railroad companies to maintain or improve the condition of roadbeds. The American Railway Engineering Association has fixed ¾ inch as the minimum and 2½ inches as the maximum for ballast sizes. The general requirements are similar to those for aggregate and road stone. Some railroad companies operate quarries of their own; others purchase the necessary stone from quarries along their lines.

Riprap.—Riprap consists of heavy irregular rock fragments used chiefly for river and harbor work, such as spillways at dams, shore protection, docks, and other similar construction that must resist the force of waves, tides, or strong currents. It is also used to fill in roadways or

[59] Woolf, D. O., The Results of Physical Tests of Road-Building Rock. U. S. Dept. of Agriculture Misc. Pub. 76, 1930, 148 pp.

low places in yards. Any type of dense, sound limestone may be used in this way. There are no general specifications covering it, but requirements for individual jobs may be enumerated. Riprap is a very low-priced product and usually is obtained from quarries situated along rivers or available to cheap coastwise transportation.

Dusting Coal Mines.—Dust explosions in coal mines are dreaded more than any other accidents by miners and operators. A coal-dust explosion is an extremely rapid burning or combustion of coal particles. The air shock travels ahead of the flame, stirs up the dust, mixes it with the air, and thus enables the flame to extend the explosion. In a dusty mine therefore an explosive wave may travel through miles of entries, shafts, and headings and cause great loss of life.

When mixed with coal dust, fine incombustible dusts make ignition of coal particles more difficult. If the inert dust equals the coal dust in amount there is practically no danger of explosion from ordinary causes, such as blow-out shots, because it practically dilutes mixtures of coal, inert dust, and oxygen to a point where continued combustion becomes difficult or impossible.

Any incombustible powder may be used for dusting, but some materials are preferred above others. Dark dusts are not desirable, as they can not be readily distinguished from coal dust. On the other hand, white dust contrasts distinctly, and the proportion of inert material present is more readily estimated. A high silica content is undesirable because silica dust is regarded as injurious to the lungs of miners. Therefore, the best dust is white, incombustible, and low in silica.

Limestone fulfills the foregoing conditions admirably. It is essentially carbonate of lime, a compound that is not considered injurious to the lungs. It can be ground to a white or light-gray powder, is abundant, and usually may be procured at low cost. The advantage of dusting coal mines as a safety measure has been urged by the Bureau of Mines, and the satisfactory service rendered by limestone has led to its wide use during recent years. Several hundred bituminous-coal mines now employ the method, and for this purpose approximately 60,000 to 70,000 tons of pulverized limestone are used annually.

Producers of limestone welcome dusting of coal mines as an outlet for waste material, because many of them are handicapped by accumulations of fines which are difficult to sell. As the material commands a low price per ton, quarries near coal fields have an advantage in this market.

A low silica content is desirable, but the screen-size specifications are not exacting. Those approved by the United States Bureau of Mines require that 100 per cent shall pass through a 20-mesh screen and 50 per cent through a 200-mesh screen.

Chalk, Whiting, and Whiting Substitutes. GENERAL FEATURES.—Chalk is defined as a noncrystalline, soft, friable, fine-grained, light-

colored type of limestone consisting essentially of calcareous shells of minute organisms known as "foraminifera." The distinguishing physical characteristics of true chalk never have been fully defined; probably its noncrystalline and colloidal properties are most important. Whiting is a pulverized, purified, carefully sized chalk. Whiting substitutes include finely ground limestone or dolomite, ground marble (marble flour), white marl, and chemically precipitated calcium carbonate.

Very little true chalk has been produced in the United States; domestic requirements are supplied from deposits in England, France, Belgium, and Denmark. A few years ago chalk was obtained from some American deposits, but very little, if any, of the present domestic production of pulverized calcium carbonate can be classed as true chalk.

Chalks of Cretaceous age occur in many places, chiefly in the Mid-Central and Southern States. Most of them contain high percentages of impurities, such as clay and sand, but several occurrences of reasonable purity have been noted. According to available records, the only production of true chalk of any consequence has been confined to Alabama. In other States, notably in Arkansas, Iowa, Kansas, Mississippi, Nebraska, South Dakota, and Texas, further prospecting and testing may develop valuable supplies. The Cretaceous occurrences of Colorado, Louisiana, Montana, and North Dakota are unpromising as sources of chalk.

Whiting substitutes, mostly in the form of finely pulverized limestone, are produced in many localities. They are used chiefly as rubber filler and less extensively in paint and putty. Generally, limestone flour that will successfully meet the requirements of fillers of a type like whiting or china clay should be ground to a powder of approximately 300-mesh grain size. Chemical purity, though not essential, is desirable, as snow-white powder is most in demand. Some companies manufacture a very pure calcium carbonate by a process of precipitation from a milk-of-lime suspension. This chemically controlled product is used chiefly as a dentifrice. Finely divided calcium carbonate obtained as a by-product of caustic soda manufactured at paper mills is used chiefly as rubber filler. In seeking a market for his product the manufacturer of whiting substitutes should be familiar with the many and varied uses of whiting, the more important of which are given in the following paragraph.

USES OF WHITING.—An important use is for calcimine and cold-water paints which contain about 80 per cent pure white whiting. True whiting is preferred because ground limestone and marble have poorer covering effects. The manufacture of putty, a mixture of 85 per cent whiting or whiting substitute with 15 per cent linseed oil, also consumes a large amount. True whiting usually is preferred for this purpose also. A third important use is as a ceramic raw material to supply the calcium oxide component of glazes and enamels or as a fluxing agent in body mixtures. Whiting is employed as a filler in numerous products, such as

rubber, paint, paper, oilcloth, window shades, and linoleum. Other products in which it is an important constituent include white ink, dressing for white shoes, picture-frame moldings, dolls, wire insulation, dyes, toothpaste, and fireworks. It is used for facing molds and cores in brass casting and as a mild abrasive for polishing metals.

PREPARATION OF MATERIALS.—Crude chalk imported from Europe is ground to a fine powder, purified, and classified by a process of water settlement, the finest and highest-grade materials being those that remain longest in suspension. The more modern mills employ bowl classifiers, thickeners, and filters.

Limestone and marble are pulverized and graded by two processes—the wet method and the dry method, but for some uses a wet-ground product is preferred. Wet grinding usually is done in pebble mills, and classification into sizes is accomplished by water settlement. Moisture commonly is driven off by means of drum driers. For dry-process grinding the crushed stone usually is passed through a rotary drier and then ground by any one of a variety of processes. Rolls or impact mills of the swinging-hammer type usually do the coarser grinding, and impact pulverizers or pebble mills the final grinding. Sometimes grading by size is done with air separators supplemented by vibrating screens. Several mills are equipped for both wet and dry processes.

Calcium carbonate obtained as a chemical precipitate is manufactured from calcium oxide (quicklime) and carbon dioxide gas. The lime is hydrated and enough water added to make a milk-of-lime suspension. The carbon dioxide gas, usually obtained by burning coke, is blown in at the bottom of the tank containing the lime suspension and, combining chemically with the lime, forms a finely divided calcium carbonate, which is prepared for market by filtering and drying.

Miscellaneous Uses. SEWAGE FILTER BEDS.—Growth of towns and cities demands increasing use of filtering materials for sewage purposes if public health is to be preserved. The function of filter stone is to supply a lodging place for bacteria which accumulate on the surface of the rock fragments and by their life processes effect purification of the sewage. Crushed limestone is satisfactory for this purpose, and large quantities are so used. The chief qualifications as described by Lamar[60] are as follows: Certain impurities, notably pyrite, marcasite, and clay, are to be avoided. If fine-grained and evenly distributed, siliceous impurities are not objectionable. Either high-calcium or dolomitic limestone may be used. Absorption should be low and pore space evenly distributed. The stone should be of uniform solubility, firmly cemented, and strong, and the fragments should have surfaces sufficiently rough to provide anchorage for bacteria. Fines and dirt should be screened out.

[60] Lamar, J. E., Limestone for Sewage Filter Beds. Illinois State Geol. Survey, Rept. of Investigations 12, 1927, 21 pp.

STUCCO AND TERRAZZO.—Dense, compact limestones of attractive colors may be crushed into small fragments for terrazzo floors. Similar material reasonably impervious to moisture finds some use in stucco and pebbledash work.

POULTRY GRIT.—Limestone crushed to granules and screened to uniform sizes is sold in considerable quantities as poultry grit. The term is a general one, for the products may be graded by sizes into turkey grit, chicken grit, pigeon grit, and bird grit. Producers reported to the United States Bureau of Mines a total of 34,600 tons, valued at $221,610, in 1929. It is probable that the figures given are low, as many operators fail to report small sales of by-products. Very few plants operate for the production of poultry grit only; it is obtained chiefly as a by-product at crushing plants. The chemical composition of the stone is of minor importance. Although pure, crystalline calcite may have some advantage in appearance, almost any type of limestone, pure or impure, may be used. In fact, one company reports a "mica crystal grit," from which one would infer that it consists of siliceous material.

It is claimed that oyster shells have exceptional virtues as constituents of poultry food, and increasing quantities are so used. Production for this use increased from a value less than $100,000 in 1918 to approximately $2,000,000 in 1931; and exports, chiefly to the United Kingdom, were valued at more than a half million dollars in the latter year. As this material is derived from shell banks it is not included in limestone statistics.

CONCRETE BLOCK FACING.—Concrete blocks made to resemble cut stone or rough stone are used widely. The resemblance to stone is increased by embedding limestone chips on the exposed surface. A small tonnage of limestone is sold for this use.

CONCRETE BLOCK AGGREGATE.—Cement, sand, and fine aggregate are mixed in various proportions in the manufacture of concrete blocks. Limestone screenings are well-adapted for use as aggregate in both concrete blocks and concrete brick.

ROAD SURFACING.—Limestone screenings are used widely for surfacing waterbound macadam roads. Fine screenings are employed also as coatings on the surface of new asphaltic pavements or in resurfacing and patching old pavements.

YARD AND PLAYGROUND SURFACING.—Screenings without a binder are used for station platforms; they afford good drainage, while footsteps of travelers and wheels of baggage trucks pack them down to a firm compact surface. Screenings are also used to surface walkways, playgrounds, school yards, and tennis courts. Fines usually are included to serve as a binder.

LIMESTONE SAND.—Limestone crushed to the size of sand grains is used as a substitute for silica sand in mortar, wall plaster, and concrete.

When carefully graded and washed, limestone sand has been employed very successfully for this purpose, but attempts to use unclassified screenings have caused some reaction against it. Mortar tests reported by Kriege[61] show strengths considerably in excess of those obtained with standard silica sands. Quite a large tonnage of limestone sand has been used in concrete highway construction in the Middle West.

ASPHALT FILLER.—Limestone dust, approximately 80 per cent of which will pass a 200-mesh screen, is the filler used most generally in road asphalt-surface mixtures, although slate flour, portland cement, and hydrated lime are employed to some extent. Many thousand tons are used in the larger cities. The preparation of asphalt filler is an appreciable part of the business of some limestone-quarrying companies, but for the most part it is regarded as a by-product activity for the utilization of fine materials that would otherwise be wasted. Annual production in the United States is about 400,000 tons, and the average price at the grinding mill is $3 to $3.50 a ton. Asphalt fillers are described in some detail by Emery.[62]

ROOFING GRAVEL.—Screened limestone chips ranging in quantity from 5,000 to 8,000 tons a year are sold as roofing gravel for use with tar on flat roofs. The average price is $2 to $2.50 a ton at point of production.

Uses for Which Chemical Properties Are Most Important. *Chemical Purity Not Always Essential.*—For all the uses enumerated in this section the chemical composition of limestone is more important than the physical properties; for some chemical purity is demanded. Thus, stone for the manufacture of lime ordinarily should contain not more than 1 or 2 per cent siliceous impurities. For certain other uses the importance of chemical composition is not to be interpreted as a demand for chemical purity; for example, limestone for cement manufacture, although it may not be pure, must have a composition that permits proper balance between the chemical constituents. Ideal cement rock contains about 20 per cent clay. For certain uses the magnesium content should be high.

Manufacture of Cement.—Limestone is the chief raw material of portland cement; in average practice about four parts of high-grade limestone are mixed with one part of clay or shale. Briefly, cement manufacture consists of calcining in a rotary kiln finely pulverized raw materials to a temperature of incipient fusion and grinding the resulting clinker to a fine powder. About 3 per cent gypsum, which serves as a retarder, is added to the clinker before grinding. The process of cement manufacture from quarry to pack house is shown diagrammatically in figure 67.

[61] Kriege, Herbert F., Washed Limestone Sand. Pit and Quarry, vol. 17, no. 11, Feb. 27, 1929, pp. 64–66.

[62] Emery, A. H., Mineral Fillers for Sheet-asphalt Paving Mixtures. Am. Inst. Min. and Met. Eng., Contrib. 17, 1933, 28 pp.

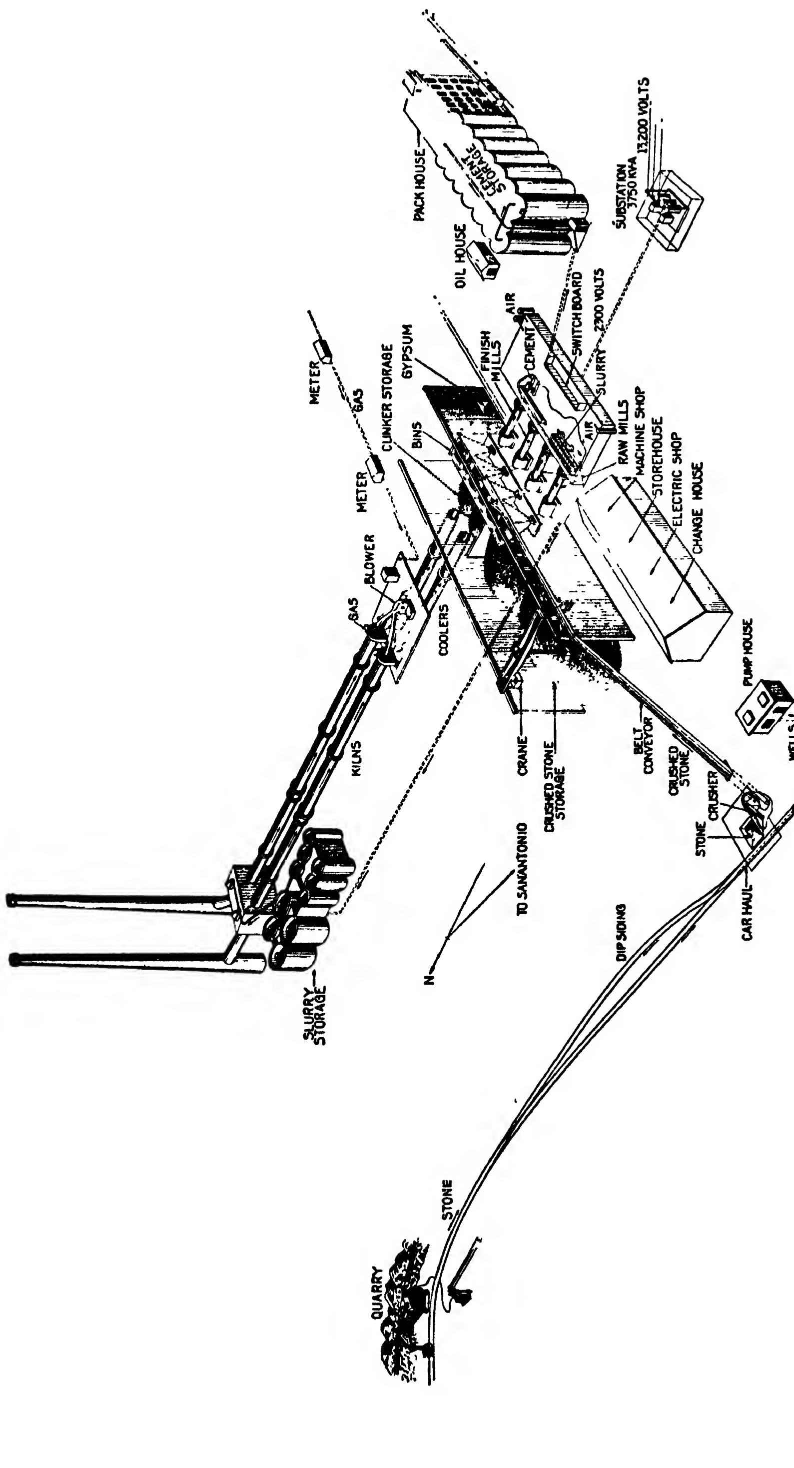

FIG. 67.—Diagram of the flow of materials through a modern wet-process cement plant. (*Courtesy of Rock Products.*)

Common massive limestone is used most generally as a raw material, but other varieties, including marble, chalk, marl, and cement rock, are employed in some places. In Virginia, Texas, and California oyster shells are used.

Cement rock is simply an argillaceous limestone, which in some localities contains enough clay as it occurs in nature to adapt it for the manufacture of cement, though sometimes it may be necessary to adjust the composition by adding small quantities of high-calcium limestone or clay. The Lehigh Valley district of Pennsylvania is an important locality for the use of cement rock.

As portland cement consists essentially of 60 to 70 per cent calcium oxide, 20 to 25 per cent silica, and 5 to 12 per cent alumina and iron oxides, evidently pure limestone is not required. Considerable percentages of silica and alumina are permissible, but to simplify the problem of proportioning the raw materials, constancy in chemical composition is desired. Although the requirements of limestone for cement manufacture are not exacting the following limitations should be observed: (1) The rock should be free of concretions of iron minerals, should contain little free silica in the form of chert, flint, or quartz veins, and should be free of silicate minerals, such as tremolite and diopside; (2) the silica and alumina contents should be low enough and in such ratio that they will not interfere with the desired silica-alumina ratio in the finished product; (3) the rock should be low enough in magnesium so that the finished product will contain not more than 5 per cent magnesia (MgO); (4) the content of iron should be sufficiently low that the ferric oxide content of the finished cement will not exceed 4 per cent; (5) the sulphur content should be low.

The manufacture of cement is a very important use for limestone, as about 45,000,000 tons are consumed for this purpose every year. Limestones suitable for cement manufacture occur in many localities, consequently the industry is widely distributed, between 150 and 160 plants operating in 33 States. The distribution of raw materials for cement manufacture is given in some detail in a report by Eckel[63] and others.

In choosing a location for a cement plant, however, an adequate supply of suitable raw materials is not the only consideration. Other factors on which success depends are markets, both local and distant, transportation facilities, and fuel supplies.

Manufacture of Lime.—Lime consists of either calcium oxide or the combined oxides of calcium and magnesium. In brief, the process of lime manufacture consists in heating limestone to a temperature at which the carbon dioxide is driven off. This process for a high-calcium limestone may be expressed by the chemical equation $CaCO_3$ + heat =

[63] See bibliography at end of chapter.

$CaO + CO_2$. In converting limestone into lime there is great loss in weight—100 pounds of pure stone yielding only 56 pounds of lime.

Most lime plants consist of shaft kilns into which 4- to 12-inch limestone fragments are dumped. Two or more fire boxes or grates are situated near the bottom of the shaft, and heat therefrom calcines the stone. The finished product sinks below the grate level and is removed from the bottom of the shaft. Lime also is manufactured in rotary kilns similar to those used in making cement.

Stone suitable for lime manufacture must conform to rather rigid physical and chemical requirements. Both high-calcium and high-magnesian limestones or dolomites are employed. High-calcium limes are used chiefly for mortars and for chemical purposes, while highly plastic magnesian limes are employed principally for finishing plasters. Magnesium therefore is not regarded as an impurity in limestone for lime manufacture. The most common impurities are silica, alumina, iron, and sulphur. Most lime now sold is manufactured from stone of exceptional purity, total carbonates ranging from 97 to 99 per cent of the rock mass. The demand for a high degree of purity in the stone is due largely to the fact that practically all impurities in each 100 pounds of stone remain in the approximately 56 pounds of lime that results from calcination. Therefore, lime manufactured from stone containing 2 per cent impurity will contain nearly 4 per cent of undesirable constituents.

The stone should be sound physically and so firmly consolidated that it may be quarried with a limited production of fine materials which are excluded from shaft kilns and are commonly wasted. Porous, friable limestones not only produce abundant fines but break down during calcination and so retard the draft that they can not be used satisfactorily in shaft kilns.

Normally, between 8,500,000 and 9,000,000 tons of limestone are used annually in the United States for manufacture of lime. A total of 381 active producers reported to the United States Bureau of Mines in 1929. The industry is widely distributed throughout the country; plants are operating in 39 States. Lime enters three important fields of utilization; in 1929, 53.7 per cent of the total production was used in the chemical industries, 38.4 per cent for mortar and plaster in the building industries, and 7.9 per cent for liming land. In the chemical industries it has so many diversified uses that it has been designated "the king of all the bases." It is claimed that lime is essential to the conduct of more than 120 manufacturing industries, but as this book deals primarily with stone in its raw state these uses are not considered.

Rockland, Me., is the most northeastern point in the country where lime is now produced. A belt extending from the Canadian border through western Vermont, Massachusetts, Connecticut, and eastern New York contains both dolomitic and high-calcium limestones. Most

of the lime produced in New York is from a belt extending across the center of the State. Both high-calcium and dolomitic limestones are widely distributed throughout the southern half of Pennsylvania, and the heavy output of many large plants throughout that district has placed the State second in rank as a producer of lime. From eastern Pennsylvania a limestone belt extends southward, supplying raw materials for important lime industries in Maryland, Virginia, West Virginia, east Tennessee, Georgia, and Alabama.

All of the Central States are well supplied with suitable limestone. A district extending 20 to 30 miles from Toledo, Ohio, is the most productive area in the country, and most of the plants utilize an almost pure

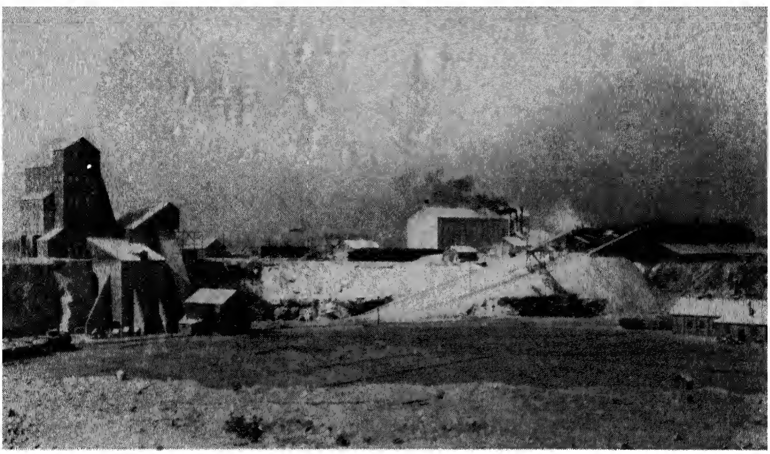

FIG. 68.—A typical Ohio lime plant and quarry with supplementary crushing and screening plant shown at left.

dolomite. Eastern Wisconsin, southern Minnesota, Illinois, Indiana, and Missouri are well provided with raw materials for numerous plants.

In the Rocky Mountain and Pacific Coast States the reserves of both high-calcium and dolomitic limestones are adequate, but commercial development is limited by the somewhat restricted demands for lime. Present activity is confined chiefly to areas near centers of population and lime-consuming industries, notably Denver, Salt Lake City, El Paso, Los Angeles, San Francisco, Seattle, and Butte. A large Ohio lime plant is shown in figure 68.

Furnace Flux.—Iron ores contain silica and alumina as impurities, and in the smelting process the addition of a basic flux, such as limestone, is necessary to remove the undesirable elements. The process of removal is based on the fact that silica and alumina have a stronger affinity for lime and magnesia than for iron; consequently, double silicates of lime and alumina, or magnesia and alumina, are fused into liquid slag which

floats on the molten iron. Sulphur in the ore, together with sulphur and ash from the coke, is also removed by slag.

As the chief purpose of flux is the removal of silica and alumina from ores it is evident that limestone employed for this purpose should be low in these compounds. If an impure stone is used, part of the carbonate content is absorbed in fluxing off foreign elements in the stone, which reduces the amount available for removing impurities of the ore. "Available carbonate" is a term applied to the percentage of calcium and magnesium carbonates left for fluxing the ore after a sufficient percentage has been deducted to neutralize impurities in the stone itself. In average blast-furnace slag the ratio of silica plus alumina to lime plus magnesia is about 1 to 1; in other words, for every pound of silica and alumina in a high-calcium flux 1 pound of lime is required to combine with and remove it as slag. A pound of lime (CaO) is derived from about 1.8 pounds of limestone ($CaCO_3$); hence, if there is 4 pounds of silica plus alumina in each 100 pounds of stone, not only is this 4 pounds of impurity lost but, in addition, four times 1.8 pounds of pure limestone, which is required to flux the impurity that is, a total of 11.2 pounds—and the available carbonate in each 100 pounds of stone is only 88.8 pounds. This may be expressed in a general formula as follows: If a equals the percentage of silica (SiO_2) plus alumina (Al_2O_3) in the stone the available carbonate is $100 - a - 1.8a$ or $100 - 2.8a$. It is evident, therefore, that a pure limestone is desirable for blast-furnace flux, the impure content commonly being limited to 5 per cent.

Economic conditions greatly influence the use of pure or impure stone. It is a peculiar circumstance that silica and alumina in a fluxing stone do no real harm in a blast furnace; they merely make the stone less effective, increase slag volume and fuel consumption, and retard production to a limited extent. If the price differential between an impure stone and one of high chemical purity is enough to offset these disadvantages an impure stone may be preferred. The sulphur and phosphorus contents, however, must be low. Sulphur should not exceed 0.5 per cent. The highest permissible content of phosphorus for Bessemer iron is placed at 0.01 per cent, and for non-Bessemer iron at 0.1 per cent.

Opinions differ regarding the slagging effect of magnesia, but generally the use of dolomites and high-magnesian limestones in blast furnaces is not objectionable. High-magnesian flux has been used successfully at Bethlehem, Pa., and Birmingham, Ala., and in many European furnaces.

Blast-furnace flux is a very important use for limestone, as about 900 pounds are required for each ton of pig iron manufactured. About 20,000,000 to 24,000,000 tons are used annually in United States iron furnaces.

A relatively small tonnage of limestone is used in basic open-hearth steel manufacture and in smelting lead, copper, and other nonferrous

ores. Basic open-hearth slags are so high in lime and magnesia that the formula for available lime reads $100 - 5.5a$, whereas for blast-furnace use, as shown previously, it reads $100 - 2.8a$. It is evident, therefore, that purer stone is required for steel-making than for blast-furnace flux; the silica content usually is limited to 1 per cent, and the alumina content to 1.5 per cent. As the chief purpose of basic open-hearth flux is to remove phosphorus, and as magnesia is a poor remover of phosphorus, the maximum permissible content of MgO usually is fixed at 5 per cent.

Owing to its enormous iron and steel industries western Pennsylvania is the chief center of production for fluxing limestone. Michigan stands second, not on account of its smelting industries, which are relatively unimportant, but because highly efficient water transportation permits shipment of the stone at low cost to many furnaces at Chicago, Gary, Toledo, Cleveland, Buffalo, and other Lake ports. Ohio is third in importance, chiefly on account of its many iron furnaces and its proximity to the western Pennsylvania smelters. Alabama ranks fourth, as large quantities of local stone are supplied to the Birmingham furnaces. West Virginia is an important producer, providing supplementary supplies chiefly for the ore furnaces of Pennsylvania. Arizona, Colorado, Illinois, Indiana, New York, Utah, and Virginia produce substantial tonnages.

Agricultural Limestone.—Limestone is important to agriculture as a fertilizer, a soil conditioner, and a corrective of soil acidity. For these purposes limestone of a high degree of purity is not essential, for although impurities decrease the percentage of calcium or magnesium available for improving the soil they are not injurious to plant growth. Therefore, local limestones, though impure may be more economical than higher-grade material from a distant source. Purity, however, is highly desirable. There is some difference of opinion regarding the suitability of dolomitic limestones, but most authorities agree that magnesium has value equal to calcium and that the agricultural value of stone may be measured by the percentage of total carbonates present. From 2,000,000 to 2,500,000 tons of ground limestone are sold annually for liming land.

Miscellaneous Chemical Uses. ALKALI.—The manufacture of sodium carbonate (soda ash) is an important chemical industry that consumes 4,000,000 to 5,000,000 tons of limestone a year. The Leblanc process, one of the older methods, involves a reaction between limestone, sodium sulphate, and carbon to form the desired sodium carbonate. A furnace charge consists of about 100 pounds of salt cake (sodium sulphate), 100 pounds of limestone, and 50 pounds of coal dust. The magnesia and silica content of the limestone should be low, or loss will ensue through formation of insoluble residues.

A more modern method is known as the Solvay or ammonia soda process. The principal reaction is in a brine (sodium chloride dissolved

in water) saturated with ammonia and carbon dioxide. The reaction may be expressed as follows: $NaCl + NH_3 + H_2O + CO_2 = NH_4Cl + NaHCO_3$. A second reaction for recovery of ammonia results from treatment of the ammonium chloride thus formed with calcium hydroxide (hydrated lime) according to the equation: $2NH_4Cl + Ca(OH)_2 = CaCl_2 + 2H_2O + 2NH_3$. Carbon dioxide used in the first reaction and lime in the second are obtained by calcination of limestone in special continuous kilns using coke as fuel. However, part of the requirement of CO_2 is obtained by calcination of the soda bicarbonate to form the normal carbonate. Chemically pure limestone is desirable, though not essential. About 1¼ tons of limestone preferably in pieces 1 to 6 inches in size are used for each ton of soda ash produced.

CALCIUM CARBIDE.—Calcium carbide (CaC_2) is manufactured by fusing an intimate mixture of powdered lime or limestone and coke in an electric furnace. About 340,000 tons of limestone were used for this purpose in 1929. About 2 tons of very pure limestone is required for each ton of carbide made. The phosphorus content should be less than 0.01 per cent because phosphorus present in carbide used for producing acetylene gas causes contamination with poisonous hydrogen phosphide. The magnesia content should be less than 2 per cent, and the silica content less than 3 per cent.

SUGAR.—Limestone is used in large quantities in refining beet sugar, particularly in Colorado and Utah. More than 488,000 tons were used in sugar factories in the United States in 1929. The limestone is calcined into lime and used in the form of a milk-of-lime suspension to precipitate impurities from the juices, or in the Steffens process to precipitate sugar in the form of tri-calcium saccharate from impure solutions. About 700 pounds of limestone are required for each ton of sugar, or, expressed in another way, the lime requirement is about 2½ per cent of the weight of beets. Although lime rather than limestone is used in the process, calcination at the refinery is desired because the carbon dioxide is recovered for use in subsequent treatment of sugar-bearing juices. Lump stone in 2- to 6-inch sizes is preferred. The presence of silica is detrimental, as it becomes colloidal in the juices and forms a film on the sugar crystals, retarding their growth and lowering their purity. Iron oxide should be low, as it affects the color of the sugar. Much limestone now used for this purpose averages 97 to 99 per cent calcium carbonate. According to a specification issued by the U. S. Bureau of Standards,[64] limestone (calcined before analysis) for the Steffens process should contain at least 90 per cent of sugar-soluble lime and not more than 3 per cent of magnesium oxide.

[64] U. S. Bureau of Standards, Recommended Specifications for Limestone, Quicklime, Lime Powder, and Hydrated Lime for Use in the Manufacture of Sugar. Circ. 207, 1925, 6 pp.

GLASS.—Either lime or limestone is used in the manufacture of glass to supply the alkaline-earth compound necessary to its constitution. Some manufacturers claim that limestone is preferable because the evolution of carbon dioxide gas is beneficial in agitating the mix; others prefer either quicklime or hydrated lime. Limestone of uniform grade is required because of the rigid control necessary in composition of the batch. In general, the lime content must not vary more than 2 per cent from that stipulated in the contract. The iron content should be low because of its coloring effect; for optical glass it must be practically zero, whereas for the lower grades of bottle glass it may be as high as 0.5 per cent. Silica is not detrimental if moderate amounts are present, but the sulphur and phosphorus content should be low. Combined calcium and magnesium oxide requirements (on a calcined basis) are about as follows: At least 89 per cent for bottle glass, 91 per cent for sheet glass, 93 per cent for blown glass, 96 per cent for rolled glass, and 99 per cent for optical glass. Magnesium in limestone makes the glass batch more difficult to melt but is advantageous in making some kinds of optical glass and is preferred where certain types of automatic machinery are employed.

RUBBER.—Limestone or its products are used in two ways in rubber manufacture—as whiting and as hydrated lime. Whiting is a bulking agent or filler, performing the same function as clay or diatomite. It also assists the rubber chemist in controlling hardness and elasticity in building up his compounds. Some rubber contains as much as 25 to 30 per cent by weight of whiting. Powdered chalk is used in the manufacture of rubber cement.

PAPER.—Manufacture of paper from wood by the sulphite process involves digestion of the pulp in an acid liquor under high temperature and pressure until all constituents but cellulose are dissolved and removed. The acid liquor, a solution of magnesium and calcium bisulphites, together with more or less free sulphur dioxide, is obtained by treating either milk of lime or wet limestone with sulphur dioxide prepared by burning sulphur or iron pyrite in air. Lime manufactured from dolomite or high-magnesian limestone is preferred for preparing acid liquor by the milk-of-lime process, because magnesium bisulphite is said to be more stable, more soluble, milder, and more effective in its chemical action than calcium bisulphite. The limestone should be pure enough to give a lime containing not more than 3 per cent total iron oxide, alumina, silica, and other insoluble impurities.

A second method of obtaining acid liquor is by the Jennsen tower system, whereby sulphur dioxide gas passes up through a tower packed with limestone. Stone for this purpose should have preferably not more than 2½ per cent magnesium carbonate, although in some cases 3 per cent may be tolerated, and rarely 5 or 10 per cent has been allowed. Other impurities should not exceed 2½ per cent, and a calcium carbonate

content of at least 95 per cent is recommended. The limestone should also be virtually free from graphite or other carbonaceous material, mica, and pyrite. Medium-grained stone in 8- to 14-inch fragments is preferred. More than 273,000 tons of limestone were used in paper mills in the United States in 1929. In addition, about 50,000 tons a year of high-magnesian lime are sold to paper mills for use in the milk-of-lime process.

FERTILIZER FILLER.—A small amount of limestone is used with commercial fertilizers as a diluting material or filler. It has the advantage over inert fillers of possessing soil correcting and fertilizing properties.

STOCK FOOD.—Pulverized limestone is added to stock food as a bone builder. Of limestone sold for miscellaneous uses in 1929, 25,270 tons were classed as mineral food.

CARBON DIOXIDE.—Use of carbon dioxide has increased greatly during recent years, chiefly because of its employment in solid form as a refrigerant. Adequate supplies are obtained principally from gas wells, coke processes, or as a by-product of chemical and fermentation industries. Dolomite is used to some extent as a source of carbon dioxide. In 1923 38,460 tons were so employed, but the amount has decreased steadily. Since 1926 no figures are available because not more than two operators reported. Vast quantities of carbon dioxide pass off from lime kilns and this source of supply is receiving more serious attention.

MINERAL WOOL.—The name "mineral wool" or "rock wool" is applied to fine interlaced threads of calcium silicate. It is comparable with slag wool or glass wool and used chiefly for heat insulation. One raw material is argillaceous limestone, classified more properly perhaps as calcareous shale. The stone is melted in a cupola furnace, and the slag thus formed issues from a small opening and is blown with a steam jet into fine threads which fall in a fluffy mass to the floor of a concrete chamber. Production has grown rapidly. Numerous plants are springing up in various parts of the country.

Uses of Dolomite and High-magnesian Limestone.—For the manufacture of a number of important products dolomite or high-magnesian limestone is essential. Some of the uses for which a magnesium content is essential or preferred are covered incidentally in preceding paragraphs, and only the more important uses are mentioned in this section.

High-magnesian Lime.—The use of limestone for manufacture of lime has been covered in some detail on previous pages. For certain building and chemical applications a high-magnesian lime is essential or preferred, and the manufacture of such lime constitutes one of the important uses of dolomite.

Refractories.—Dolomite and high-magnesian limestone are used extensively as refractory linings in metallurgical furnaces, chiefly in

basic open-hearth steel furnaces. Dead-burned material in various forms is commonly used, although raw dolomite may be employed for repair work. A dead-burned product is made by calcining dolomite or high-magnesian limestone at about 1,500°C. either in a blast furnace or in a special kiln. Virtually all the carbon dioxide is driven off, and the calcium and magnesium oxides are sintered to an extent depending upon the impurities present. Certain agents, such as iron oxide, alumina, or silica, may be added to aid the sintering action.

There are two general ways of utilizing dolomite in furnace work; it may be mixed with tar or a fluxing agent and applied as a monolithic lining, or the calcined dolomite to which tar or suitable fluxing agents are added may be shaped into bricks which are fired and then laid in the same manner as other refractory brick.

Where dead-burned dolomite is used as a substitute for dead-burned magnesite in basic furnace bottoms the raw stone should contain less than 1 per cent silica, less than 1.5 per cent combined iron oxide and alumina, and at least 35 per cent magnesium carbonate, the remainder being calcium carbonate. For this purpose dolomite is somewhat inferior to grain magnesite; but it is satisfactory for repair work, which requires 40 to 50 pounds per ton of steel. More than 1,490,000 tons of dolomite were used for refractory purposes in the United States in 1929. The amount fell greatly in 1932 but reached 1,800,000 tons in 1937.

Technical Carbonate.—Technical carbonate, known also as basic magnesium carbonate, block magnesia, or magnesia alba, finds its widest utilization in the manufacture of pipe and boiler covering and for general heat insulation, but it is also used in pharmacy, in the rubber trade, and as a constituent of certain paints, varnishes, glass, printing inks, tooth paste, and other commodities. It is manufactured chiefly from dolomite by the Pattinson process or some modification of it. The process may be outlined briefly as follows:

Dolomite is mixed with coke and calcined, and the carbon dioxide thus driven off is recovered, purified, compressed, and cooled. The calcined stone, consisting of a mixture of calcium and magnesium oxides, is slaked in water and recarbonated with the recovered carbon dioxide. The reaction results in formation of an insoluble calcium carbonate and a soluble bicarbonate of magnesia having a composition expressed by the formula $Mg(HCO_3)_2.H_2O$. The calcium carbonate is removed by filtration, and the filtrate is boiled, which drives off some of the carbon dioxide and precipitates a white basic magnesium carbonate (the so-called technical carbonate), a product somewhat variable in composition but considered as having the formula $4MgCO_3.Mg(OH)_2.5H_2O$.

For manufacture of the so-called "85-per cent magnesia" molded insulation, technical carbonate is mixed with about 15 per cent by weight of asbestos fiber and possibly other bonding agents, molded into the

desired form, dried for five or six days, and finally cut to true dimensions with special machinery. According to United States Bureau of Mines figures, 84,750 tons of dolomite were used for manufacture of technical carbonate in 1929, 111,740 tons in 1930, 80,820 tons in 1931, and 96,730 tons in 1937.

INDUSTRY BY STATES

General Distribution.—Limestones occur in every State. In some States hundreds of deposits are quarried and prepared for the numerous uses described on previous pages. The principal limestone areas of the United States east of the Rocky Mountains are shown in figure 69. The stone in these areas is of almost inestimable importance to industry, and high-grade deposits are assets of great value to any community within easy reach of possible consumers. The discussion of deposits herein relates primarily to sources of crushed and broken stone. Deposits of building limestone and marble described in previous chapters also are potential or actual sources of crushed products, and to obtain an adequate picture of the resources of any State the occurrences described in the chapters on building limestone and marble also should be considered.

In following pages the distribution of limestone deposits is covered by States in alphabetical order. For some of the more important States tonnages or values for certain years are given to indicate the extent of the limestone industries. Statistics of production for the several States are published annually by the United States Bureau of Mines.

Alabama.—Chickamauga limestone of Ordovician age occurs in parallel bands along river valleys in northern Alabama. The principal occurrences are in Jones, Murphrees, Cahaba, Big Wills, and Coosa Valleys. Although not quarried extensively it is sufficiently pure for lime burning and for flux at several iron furnaces. Limestone of Ordovician age is used for cement manufacture at Leeds, Jefferson County; and at Ragland, St. Clair County. Cement plants at Birmingham use Cambrian limestone with clay, shale, or slag.

Mississippian (Lower Carboniferous) limestone outcrops along the sides and at the base of plateaus in the same general region occupied by the Chickamauga beds but at a higher level. In many places it has a high degree of purity and is, or has been, quarried extensively for iron-furnace flux, notably near Rockwood, Franklin County; Bangor, Blount Springs, and Graystone, Blount County; Rock Springs, Etowah County; and Trussville, Tarrant, and Compton, Jefferson County. Dolomite for refractory use also is quarried at Ketona and New Bessemer in this county and calcined at Ensley. Longview and Newala limestones of Ordovician age are the chief sources of stone for an important lime-burning industry centered in Shelby County south of Birmingham. Lime is manufactured at Graystone, Blount County.

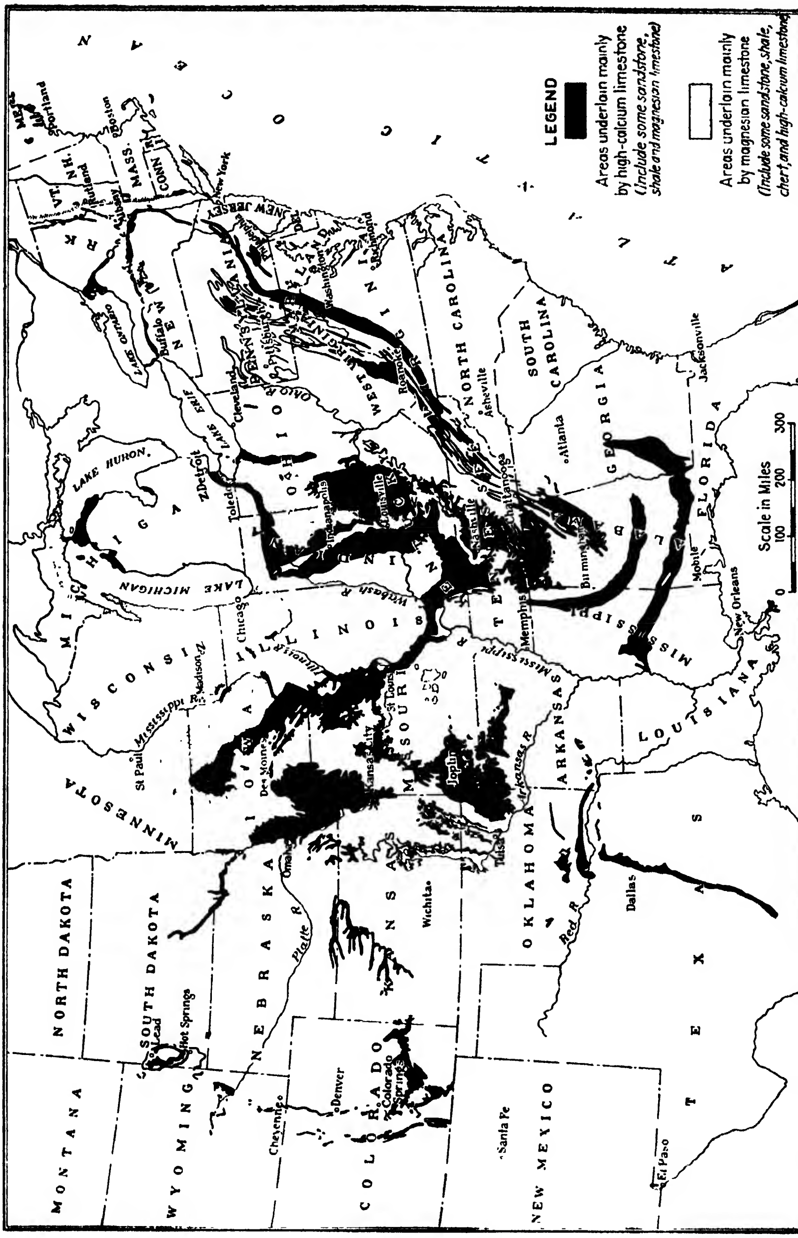

FIG. 69.—Map showing principal limestone areas east of the Rocky Mountains. (*After Burchard and Emley, The source, manufacture and use of lime; Mineral Resources of the United States*, 1913, *Pt.* 2, *p.* 1510.)

White crystalline Cambrian or early Ordovician marbles occurring in a belt in Talladega County are very pure, containing 99 per cent or more calcium carbonate. Although they are used principally for building and ornamental stone, they are suitable for furnace flux and have been so used. Waste marble is crushed and pulverized for many uses.

The Selma Chalk of Upper Cretaceous age, extending across central Alabama, is too friable for uses other than those demanding finely divided material. The chalk beds have been quarried for whiting manufacture, and a cement plant near Demopolis, Marengo County, utilizes calcareous stone from this formation.

The St. Stephens limestone of Tertiary age crosses southern Alabama and extends into Mississippi, where it is known as the Vicksburg limestone. It is softer, more uniform in composition, and higher in calcium than the Selma Chalk. While suitable for cement manufacture, little of it is hard enough for high-grade crushed stone. A cement plant at New Orleans, La. is supplied with stone from this formation. It is quarried at St. Stephens on the Tombigbee River, Washington County, and is shipped by water.

Aside from that employed in cement and lime manufacture about nine tenths of all the crushed and broken limestone produced in Alabama is used as furnace flux for the great iron industry of Birmingham. Crushed stone for road material, concrete aggregate, and railroad ballast is obtained chiefly from the Mississippian beds of northern and central Alabama, with minor supplies from the Cambrian, Chickamauga, and St. Stephens beds. Crushed stone is produced at Florala, Covington County; and at Bridgeport, Jackson County.

A bituminous oolitic limestone of Mississippian age is quarried near Margerum, Colbert County. The best of the quarry product, that which is highest in bitumen, is enriched with the addition of 4 to 5 per cent petroleum asphalt and sold as ready-mixed paving material. The leaner product is sold as crushed stone. Lime is also manufactured at Margerum.

Arizona.—The Arizona limestones have been developed only in a small way. Cretaceous limestone is quarried near Douglas, Cochise County, for production of flux, lime, crushed stone, and agricultural limestone. Beds of Carboniferous age near Nelson, Yavapai County, are utilized for the manufacture of lime. Stone from the same formation is quarried at Perkinsville and calcined into lime, chiefly for use in the Clarkedale smelters. A new lime plant is in prospect near Tucson, Pima County. Its supply of stone is 7 miles west of the city. Lime for metallurgical uses is manufactured at Radium, 7 miles north of Miami, Gila County. By-product crushed stone and fines are used for concrete aggregate and as stone sand and railroad ballast. Fluxing limestone and small quantities of lime are produced at Tempe near Phoenix,

Maricopa County. Some years ago the United States Government operated a cement plant to supply material for building the Roosevelt Dam, but upon completion of the project the plant was abandoned.

The smallness of the limestone industry in Arizona probably is due more to restricted markets than to lack of raw materials.

Arkansas.—The principal limestone area of Arkansas lies in the northern part of the State, in the Ozark Plateau region. High-calcium rocks are represented in several formations, chiefly the Plattin, Kimmswick, and Ferndale, of Ordovician age; the St. Clair (Silurian); the Boone and Pitkin (Mississippian); and the Brentwood and Kessler, of Pennsylvanian age. The Boone formation, with a maximum thickness of 425 feet, extending from White County to the Oklahoma line, is the most important. It is utilized for the manufacture of lime at Johnson, Washington County; Ruddells, Izard County; Limedale, Independence County; and St. Joe, Searcy County. Crushed stone and agricultural limestone are manufactured at St. Joe, and stone quarried at Williford, Sharp County, is used for agricultural limestone, aggregate, and ballast. High-magnesian limestones of Lower Ordovician age are plentiful in the Ozark region.

The Annona and Saratoga Chalk formations, both of Upper Cretaceous age, occur prominently in Southwestern Arkansas. In places the rock is, or closely simulates, true chalk. In past years it has been ground quite extensively at Whitecliffs, Little River County, for agricultural limestone and as whiting or whiting substitute for various filler uses. The Annona attains a maximum thickness of 100 feet and is higher in calcium than the Saratoga. It is used for cement manufacture southwest of Nashville, Howard County. Cretaceous chalk will supply raw material for a new cement plant which was under construction in 1932 at Foreman, Little River County.

California.—Several geologic periods are represented by the California limestones. In the more northerly section they are of Paleozoic age. In the Coast Ranges the more important limestones are of early Jurassic (pre-Franciscan) age; and in the Sierra Nevada foothill belt limestones occur in lenses in the Calaveras (Mississippian) formation or its equivalent. At several places in the central district north and east of San Francisco Bay travertine bodies of recent age have been deposited by springs near eruptive rocks. Some of them cover fairly large areas surficially but are relatively thin.

Few extensive limestone deposits comparable with those in many of the eastern States occur in California. Most of them are irregular, lenticular bodies of variable magnesia content. Mining or quarrying problems often are difficult, and many deposits are far from markets. Numerous comparatively small areas of shelly, compact, or crystalline limestones outcropping in many counties supply the chief raw materials

for important cement and lime industries, but various igneous rocks are used more widely than limestone as sources of crushed stone. Nevertheless, crushed and pulverized limestones are utilized in many ways, including stone for concrete aggregate, road construction, railroad ballast, flux, refractories, glass and sugar manufacture, agricultural use, roofing gravel, terrazzo, chicken grit, whiting, and whiting substitute. Both the extreme northern part of California and the desert regions in the south have larger deposits of limestone than the more populous parts of the State, but owing to distance from markets and inadequate transportation facilities they have little or no commercial value.

Lime and crushed-limestone products sold in California in 1929 were valued at over $1,100,000 and cement nearly $23,000,000. In 1937 the figures were, respectively, $2,037,540 and $17,900,739.

Cement manufacture, centered in about a dozen localities, is an important industry. Proximity to the extensive Los Angeles markets has encouraged operation of large plants at Colton and Victorville and construction of a new mill near Amboy, all in San Bernardino County. Other large plants are near Crestmore and Oro Grande, both close to the boundary between San Bernardino and Riverside Counties. Plants near Los Angeles, Los Angeles County, and at Monolith, Kern County, use local raw materials. San Juan Batista, San Benito County, is an important center. Limestones adjacent to the coast are utilized in a plant at Davenport, Santa Cruz County. Oyster shells pumped from San Francisco Bay are used for cement manufacture at Redwood City, San Mateo County. The shell deposits contain both the lime and clay necessary for a proper cement mixture. Local limestone is consumed by a plant at Cowell, Contra Costa County. Some years ago limestone was quarried for cement manufacture near Suisun, Solano County, but this source of supply proved unsatisfactory. Until 1929 cement continued to be manufactured in this locality, but the stone was shipped 85 miles from Auburn, Placer County. Limestone obtained at El Portal, Mariposa County, is shipped 63 miles to a plant at Merced, Merced County. An isolated area of limestone 12 miles long and about ½ mile wide is quarried for a mill at San Andreas, Calaveras County.

The most southerly lime plants of California are at Westend, Colton, and near Ludlow, San Bernardino County. Lime is made from local stone at Rincon and Felton, Santa Cruz County; and near Concord, Contra Costa County. A plant using oyster shells as raw material began operation in 1931 at Newark, Alameda County. A comparatively large deposit of limestone crossing the western end of Tuolumne County is utilized for lime manufacture at Sonora. Other lime plants are at Diamond Springs and near Auburn, El Dorado County; and at Kennett, Shasta County.

Crushed and pulverized limestone products are obtained in quite a number of important areas. As the deposits and production centers are scattered, they are considered by counties, beginning in the southern part of the State.

The limestones of Los Angeles County are used as fluxing stone and asphalt filler and for road stone and sugar manufacture. San Bernardino County deposits not only supply important cement and lime plants, mentioned previously, but are quarried for various crushed-stone products at Westend and Victorville. Both limestone and dolomite quarried near Monolith, Kern County, are shipped to Los Angeles markets. A dolomite deposit near Lone Pine, Inyo County, is quarried for the manufacture of alkali and other products and for use as a steel-furnace refractory. Limestone obtained near Lemoncove, Tulare County, is used principally in agriculture, for glass factories, and as a finely pulverized product for the filler trade. A dolomite deposit near Salinas, Monterey County, is worked at times for production of agricultural limestone and refractories. At Hollister in the same vicinity limestone is quarried and crushed for a variety of uses. For several years oyster shells have been pumped from San Francisco Bay and conveyed to Alviso, Santa Clara County, where they are ground for poultry grit and agricultural limestone. The latter product is prepared also near Concord, Contra Costa County; and at Sonora, Tuolumne County. An attractive red travertine quarried near Bridgeport, Mono County, is used for terrazzo. Crushed stone, fluxing stone, whiting substitute, and limestone for chemical plants and sugar mills are obtained near Diamond Springs and Shingle Springs, El Dorado County. The only important commercial crushed-stone development in the comparatively large limestone deposits of northern California is at Kennett, Shasta County, where smelter flux and agricultural limestone are produced as occasion demands.

Colorado.—The Colorado limestones may be divided conveniently into two groups—an eastern division, mostly of Cretaceous age, forming a belt immediately east of the Front Range, and a second division, mostly of Carboniferous age, lying west of this range. The Cretaceous formation consists of two members, the Niobrara and the Greenhorn; the former is the more extensive.

The Niobrara limestone outcrops continuously from north of Fort Collins to the middle of Douglas County, passing a little west of Denver. From this location to a point 10 miles south of Colorado Springs the outcrop is much interrupted by faulting and overlap of later formations. It occupies quite a large area in southwestern El Paso County, the eastern end of Fremont County, much of Pueblo, Otero, Huerfano, Las Animas, Bent, Prowers, and Kiowa Counties, and a small area in Cheyenne County. The best rock contains more than 90 per cent total carbonates,

but most of the formation is intermixed with shale. Some of the Carboniferous limestones west of the Front Range are pure enough for even the highest-grade uses, but their location has discouraged commercial development.

Exploitation of limestone deposits has been confined chiefly to a central area, comprising El Paso, Pueblo, Fremont, and Chaffee Counties, and all the quarries except those of Chaffee County are in the Niobrara formation. Lime is manufactured at Manitou, El Paso County, and produced in a small way at Pueblo, Pueblo County, but chief operations in the latter county are near Stone City, where large quantities of furnace flux are produced. In Fremont County stone is quarried at Concrete and Portland for cement manufacture and at Canon City chiefly for furnace flux, with smaller amounts for sugar factories, agriculture, and highway construction. Dolomite is quarried for use as a refractory lining in furnaces. Large quantities of fluxing stone for the smelting industry at Pueblo are obtained from Carboniferous beds near Monarch and Garfield in southern Chaffee County, where limestone for sugar factories is also produced. At the travertine quarries near Salida crushed material is sold and some lime is manufactured as by-products of a building-stone industry. Magnesian limestones near Leadville, Lake County, have been used for smelter flux.

The largest operation outside this central district is for the production of stone to supply a cement plant at Boettcher near Fort Collins, Larimer County. Stone for sugar mills is obtained from the Ingleside formation of Carboniferous age at Ingleside.

A small production of lime and fluxing limestone has been reported at Durango, La Plata County, near the southwest corner of the State from beds of Carboniferous age.

Connecticut.—The only important calcareous rocks of Connecticut are the Stockbridge crystalline limestones of Cambro-Ordovician age at the western border of the State. They extend from Canaan in northern Litchfield County southward beyond Danbury, Fairfield County. Small outcrops of limestone reported in other parts of the State have little commercial importance. As most of the Stockbridge limestone is dolomitic it is unsuitable for cement manufacture. The crushed-limestone industry of Connecticut is very small, because trap rock is much more abundant and gives excellent service for road construction, concrete aggregate, or railroad ballast.

The Litchfield County dolomites are utilized principally for lime manufacture. At least five large lime plants near Canaan, East Canaan, and New Milford have been in operation during recent years for the manufacture of high-magnesian lime, with a minor output of low-magnesian lime. There is also in this county a small production of agricultural limestone and filler.

Near Danbury, Bethel, and Redding, Fairfield County, both high-magnesian and low-magnesian limestones are crushed or ground for road stone, concrete aggregate, aggregate for the manufacture of cast stone, poultry grit, agricultural limestone, and filler.

Delaware.—Small areas of crystalline limestone, mostly dolomitic but with variable magnesian content, occur in the extreme northern part of Delaware. They are of no present commercial importance.

Florida.—Calcareous rocks, all of Eocene age or later, are distributed widely in Florida. The Ocala limestone, of Eocene age, a high-calcium rock occurring in very pure form in places, outcrops or is available near the surface in the northern part of Jackson County, also in central Florida over a large area comprising part or all of Suwannee, Lafayette, Gilchrist, Alachua, Dixie, Levy, Marion, Sumter, and Citrus Counties. The Marianna limestone, of Oligocene age, a high-calcium stone of which some is soft and chalklike, occurs only in a small area at Marianna, Jackson County. The Glendon limestone, also of Oligocene age, a compact white rock, quite hard in places, occurs in the northwestern part of Florida in parts of Holmes, Washington, and Jackson Counties, and less extensively farther east in Madison, Suwannee, and bordering counties. Tampa limestone, of Miocene age, a fairly hard, compact, light gray to yellow rock, occurs typically in parts of the west-central counties—Citrus, Hernando, Pasco, Pinellas, and Hillsborough. A large area occurs also in northern Florida, in Suwannee, Hamilton, Madison, Lafayette, Taylor, Jefferson, Leon, and Wakulla Counties. Coral and oolitic limestones, of Pleistocene age, form the foundation of the keys from Miami to Key West and border the eastern side of the Everglades. Coquina and related shell limestones, of Pleistocene and Recent age, occupy a large part of southern Florida, as well as sections of several northern counties, particularly along the coast.

Chief production is in the Ocala formation of central Florida in Marion, Levy, Alachua, and Citrus Counties. Near Reddick, Kendrick, and Ocala, Marion County, limestone is quarried for road construction, railroad ballast, and agricultural use. In response to the rapidly increasing demands of building construction in Florida an important lime industry has grown up during recent years at Ocala and Reddick. Several large crushed-stone plants at Raleigh, and Williston, Levy County, and York, Marion County are producing concrete aggregate and road stone. Similar quarries are worked in Alachua County. A crystallized limestone widely used for concrete aggregate is quarried at Crystal River, Citrus County.

Chief developments in northwestern Florida are at Marianna and Cottondale, Jackson County, where stone for agriculture and for highway construction is quarried in large quantities. Another important production center is Hernando County on the west coast. Limestone, of the

Tampa formation, is quarried near Brooksville and shipped by rail about 50 miles to Hooker's Point near Tampa, where it is manufactured into cement in Florida's one cement plant. Crushed stone for railroad ballast and concrete aggregate is also produced in the Brooksville district.

In Dade County, both near Miami and farther south at Naranja, large quantities of limestone and dolomite are crushed for ballast and road construction. Road stone is produced in Suwannee and Volusia Counties and shell marl in Glades County. Road stone was produced near Fort Lauderdale, Broward County, in 1930. Near Jacksonville, Duval County, dredges are employed to obtain submerged calcareous building sand, fertilizer sand, and oyster shells.

Georgia.—Commercial limestones of Georgia are confined principally to the northwestern counties. Cambrian and pre-Cambrian crystalline marbles of the Piedmont occur extensively in Fannin, Gilmer, Pickens, and Cherokee Counties. The great marble industry of Georgia is centered in Pickens County. West of this crystalline belt in counties constituting the Appalachian Valley district of Georgia limestones are abundant and of great economic importance. Geologically, they comprise the Conasauga and Beaver limestones, of Cambrian age; the Knox dolomite, of Cambro-Silurian age; the Chickamauga limestone, of Silurian age; and the Floyd and Bangor limestones, which have been assigned to the Carboniferous period. Limestones, of Tertiary age, occur in many parts of the great Central Plain area of southern Georgia, but most of them are thin-bedded, argillaceous limestones or marls for which uses are limited.

An industry of some importance has been developed in Pickens County through utilization of pure high-calcium waste marble. It is crushed for flux, aggregate, terrazzo, stucco, and poultry grit, ground for agricultural use, or pulverized to an impalpable powder for filler or whiting substitute. The marbles of Gilmer County at times are crushed for road stone and terrazzo and the fine materials sold for soil improvement.

Limestones of Polk, Dade, and Bartow Counties of the Appalachian Valley now have the greatest commercial importance. They furnish calcareous raw materials for two large cement plants in Polk County, one each at Portland and at Rockmart. Crushed limestone is also produced in this county. An important lime industry has been established at Ladds near Cartersville, Bartow County. The quarry, which provides stone for lime manufacture, also supplies a large tonnage for road work, agricultural use, chemical applications, and asphalt filler. A marble-flour industry of some importance is conducted at Cartersville. Pure, high-calcium marble waste is shipped from Pickens County or from Alabama and ground by wet or dry methods to produce marble flour for the paint trade or for the varied uses of whiting and whiting substitute. Road stone is produced at Graysville, Catoosa County.

Coastal Plain limestones are quarried most extensively in Houston County. They supply raw material for a cement plant at Clinchfield and are quarried on a large scale near Perry to produce road stone. Crushed-stone output is reported at times from Crisp County, and from Sandersville, Washington County. The above producing areas are near the center of the State. At Cuthbert, Randolph County, farther southwest, travertine chips have been sold for terrazzo and ground travertine for agricultural use.

Idaho.—Limestone deposits are to be found in many parts of Idaho, those of chief value occurring in the northwestern and southeastern counties. Cambrian limestones in Bannock County near the southeastern corner of the State have assumed importance owing to their utilization for cement manufacture in a plant at Inkom, which began operation in 1929. Crushed stone for lime manufacture, aggregate, and flux has been produced near Pocatello in the same county, and stone has been quarried in Cassia County for lime burning and for supplying sugar refineries.

In northwestern Idaho lime is manufactured near Bayview in the extreme northeastern corner of Kootenai County. Small amounts of flux, chicken grit, and agricultural limestone are also produced in this locality. A nearby quarry at Lakeview, Bonner County, supplies a large tonnage of stone which is shipped to Spokane, Wash., for the manufacture of cement.

Limestones, probably of Triassic age, occur along Snake River in Nez Perce County and have been quarried near Lewiston for agricultural stone, chicken grit, stucco, and terrazzo. Farther east, at Orofino, Clearwater County, the above products, as well as lime, are produced. Pure limestone from Butte and Teton Counties is or has been shipped to sugar factories in Idaho and Utah.

Illinois.—Commercial limestone deposits occupy about one third of Illinois, including the northern end and a belt along the western and southern borders. Scattered deposits of minor economic importance occur in the remaining two thirds of the State. The northern area, which contains an abundance of Ordovician and Silurian limestones, includes Whiteside, Lee, La Salle, Grundy, and Kankakee Counties and all those north of them. Most of the rock in this area is dolomitic. The greater part of the crushed-stone industry of Illinois is centered in this area, within a radius of 75 miles of Chicago. The western district comprises a narrow strip along the Mississippi and lower Illinois Rivers, extending from Rock Island to Randolph County. Nearly all the limestones are of Carboniferous age, chiefly Mississippian. The southern district, comprising 10 counties, also contains prominent Carboniferous limestone deposits, with minor exposures of Devonian age.

Illinois produces annually about 5,000,000 tons of crushed stone for aggregate, road stone, and ballast and more agricultural limestone than any other State. Important cement industries are situated at La Salle and Dixon. Lime production is centered chiefly near Quincy, Cordova, and Chicago.

The limestones of each district are described briefly by counties in alphabetical order, but for the sake of brevity several counties where production is small are omitted.

Northern District.—The dolomites of Boone County were worked quite extensively at one time for local building stone, but at present they are quarried only for crushed stone at Belvidere. An abundance of limestone occurs in the Chicago district of Cook County. It is very important because of the immense demand for road, street, and building material in that populous center; it is used also as riprap for harbor work. Some of the largest, best-equipped limestone plants in the country are to be found at the suburban towns Bellewood, McCook, Lamont, La Grange, Lyons, and Thornton. Lime is burned in and about Chicago; but much of the raw stone is purchased, and some is obtained by water from Calcite, Mich. A considerable quantity of the crushed limestone utilized in the Chicago district is taken from the spoil banks of the canal along the Des Plaines River. Railroad ballast, aggregate, filter stone, and agricultural limestone are produced in large quantities at Elmhurst, Du Page County, from thick dolomite beds adjoining those in Cook County.

A fine-grained, dense, white dolomite occurs in Kankakee County and is quarried extensively near Kankakee for road stone, concrete aggregate, and agricultural limestone. Other small quarries are operated for local use. Available limestone outcrops in Kendall County generally are small, but locally the larger deposits are quarried for crushed stone and agricultural limestone. La Salle County is characterized by an extensive occurrence of low-magnesian Carboniferous limestone associated with shale. It supplies raw material for an important cement industry near La Salle and Oglesby. Two cement plants obtain their stone from open-pit quarries, while one has extensive underground and open-pit workings.

Unlike most limestones of the northern district, the Platteville rock, of Ordovician age, occurring in northwestern Lee County, is locally of the high-calcium type. It is a fine-grained, dense, blue-gray stone in beds 2 to 40 inches thick. A large open-pit quarry supplies stone for a cement plant at Dixon. Galena and Platteville dolomite occurs in the same vicinity, but no crushed stone is produced, except occasionally from numerous small quarries.

An abundance of Silurian limestone underlies practically the entire area of Will County, but the overburden is too heavy for profitable work, except near the western side. The rock is a white, light gray, or

buff dolomite in beds aggregating about 200 feet or more in thickness, though quarry faces are only 25 to 90 feet high. All the active quarries are near Joliet, and some are very large and well-equipped. The chief products are aggregate, road stone, and ballast, with a minor output of agricultural limestone, filter-bed stone, and screenings. Crushed stone, agricultural limestone, and lime are, or have been, produced from the Galena formation at Rockford and elsewhere in Winnebago County near the northern border of the State.

Western District.—Large, important lime industries are centered near Quincy and Marblehead, Adams County. Keokuk-Burlington (Mississippian) limestone occurs beneath so heavy an overburden that it is available only along the river bluffs. Underground mining is now generally followed. Part of the stone mined is used for lime manufacture and the remainder crushed for aggregate and chicken grit or ground for agricultural limestone and filler. A substantial production of riprap and crushed stone is reported from Golden Eagle, Calhoun County; and also from Grafton, Jersey County. High-calcium Mississippian limestone is quarried near Eldred, Green County, for road material, concrete aggregate, and agricultural limestone and flour, with a small production of poultry grit.

Fine-grained gray to white Mississippian limestone occurs in Madison County but is covered with a mantle of drift or loess averaging about 40 feet thick, except where the rock beds are exposed along the river bluffs. The rock is quarried quite extensively for road material, concrete aggregate, and agricultural limestone. One large quarry at the top of the bluff provides stone for glass making and agricultural use and for grinding to a very fine powder as a filler for paint, putty, rubber, and asphalt. Road stone is quarried near Livingston.

Mississippian and Ordovician limestones occur in Monroe County. The former are crushed for concrete aggregate, road material, ballast, and agricultural limestone. The Ordovician limestones, however, are regarded as too soft for road stone but are well-suited for aluminum-refinery flux or for agricultural limestone uses. The chief production is near Columbia and Valmeyer, where quarries are operated in the Mississippian and Ordovician formations, respectively.

Limestones in Randolph County are available in thick beds along the Mississippi River. Recent production has been confined principally to the prison quarry at Menard, where agricultural limestone, concrete aggregate, and road stone are obtained. Niagara (Silurian) limestone is quarried for manufacture of lime and for crushed stone near Cordova, northern Rock Island County.

St. Clair County, in the East St Louis district, is a very active quarry center. Mississippian limestone outcrops extensively in the western part of the county, and very large quarries are worked near Columbia,

at Stolle, and at Falling Spring 1½ miles north of Columbia. The chief products are aggregate, ballast, road stone, flux, chemical stone, and agricultural limestone.

Southern District.—At Shetlerville, Hardin County; near Cypress, Johnson County; and at Anna, Union County, a lower Mississippian limestone, the massive Ste. Genevieve formation, is quarried for road stone, concrete aggregate, agricultural limestone, and riprap.

Indiana.—Limestone occurs very widely in Indiana and is available in many geological formations. Ordovician, Silurian, and Devonian limestones appear in various counties in the southeast. The most important are the Mississippian beds, which form a belt about 20 miles wide extending northwest through the central part of the State to the Illinois line. Some limestone beds occur in the Upper Carboniferous (Pennsylvanian), and Quaternary marls have been utilized quite extensively for the manufacture of cement in northern Indiana.

Regardless of the well-known building-limestone industry the quarrying of limestone and its manufacture into crushed-stone products are important industries in Indiana. The value of crushed stone for aggregate, road material, and ballast amounts normally to about $3,500,000 a year. Indiana usually stands second to fourth in rank among all the States as a cement-manufacturing center and normally about eight lime plants are in operation.

The industries as now constituted may be considered most conveniently by counties grouped in certain geographic areas, as follows: South and southeastern, eastern, south-central, north-central, north and northwestern. Such grouping is in no sense permanent, for new developments or the inactivity of some plants now producing might lead to an entirely different alignment.

South and Southeastern Area.—A large output of aggregate, agricultural limestone, and ballast originates near Marengo, northeastern Crawford County, and at St. Paul and New Point, Decatur County. Lime is produced in northwestern Harrison County not far from Milltown and crushed stone in the same district. Road stone and aggregate are reported from Jefferson County; Washington, Daviess County; Vernon, Jennings County; and Napoleon, Holton, and Osgood, Ripley County. Salem, Washington County, is the center of a large lime and crushed-stone manufacturing industry; and cement is manufactured at Speeds, Clark County. Large quarries for road-stone production are at Charlestown and Sellersbury, Clark County. There are mineral-wool plants at Campbellsburg and Salem, Washington County.

Eastern Area.—Road stone, aggregate, and other products are obtained at Linngrove, Adams County; and near Muncie, Delaware County. The manufacture of lime is an active industry at Huntington, Huntington County, where large quantities of ballast and road stone also

are produced. Stone for aggregate, road building, and agricultural use is quarried near Portland, Jay County; and near Ingalls, Madison County. A calcareous rock high in silica and alumina occurring near Alexandria, Madison County, near Wabash and Lagro, Wabash County, and at Yorktown, Delaware County, is melted in cupola furnaces and manufactured into mineral wool. Quarries for the production of road stone and aggregate, some of which are of large size, are situated near Albany and at Ridgeville, northern Randolph County; near Glenwood, Rush County; and at Bluffton, Wells County.

South-central Area.—The greatest building-limestone industry in the world is centered in Lawrence and Monroe Counties. Large, irregular blocks of stone obtained in many quarries of both counties are sold as riprap; and stone is prepared at various points for flux, agricultural uses, glass factories, road stone, and other applications. Lime is manufactured at Bedford. These commodities are to be regarded chiefly as by-products of the building-limestone industry. Road stone and aggregate are produced at Spencer, Owen County, and a large output of similar products originates near Greencastle, Putnam County. Important cement-manufacturing industries are located near Greencastle, Putnam County, and at Mitchell, Lawrence County.

North-central Area.—A large rotary-kiln lime plant operates at Keeport near Logansport, Cass County. Extensive quarries for production of ballast, aggregate, and road stone are operated near Kenneth and Logansport, Cass County; and at Kokomo, Howard County.

North and Northwestern Area.—Rensselaer, Jasper County, and Kentland, Newton County, are centers of crushed-stone production. Railroad ballast and concrete aggregate are produced near Monon, White County. At Stroh, La Grange County, a cement plant is in operation, the chief raw material used being marl dredged from low-lying areas. Marl formerly was used for the manufacture of cement much more extensively than at present. A very large cement plant at Buffington, Lake County, uses no local stone; its raw materials consist of slag from the Gary furnaces and limestone shipped from Calcite, Mich.

Iowa.—Limestones are very plentiful in Iowa. The oldest sediments, those of Cambrian age, occur in the northeastern counties, and formations of successively later ages appear to the west. The eastern Cambrian and Silurian limestones are almost without exception high in magnesia, and most of the Ordovician calcareous rocks are likewise dolomitic. The Devonian limestone of east-central Iowa is magnesian in the northern part and high-calcium in the south. Carboniferous limestones in central and southern Iowa are low in magnesia. Chalk beds of Cretaceous age occur in the valley of the Big Sioux River in the western part of the State.

Stone produced in Iowa in 1930 for concrete aggregate, road material, and ballast was valued at more than $1,500,000, and almost all of it was

limestone. Cement manufacture is important; normally six plants produce 6,000,000 to 7,000,000 barrels annually.

Limestone quarries are most numerous in eastern Iowa, active operations being conducted in many counties. Quarries (some of which are large and well-equipped) for the production of concrete aggregate, road stone, agricultural limestone, ballast, and flux are operated more or less continuously near Lansing, Allamakee County; La Porte City, Black Hawk County; Waverly, Bremer County; Marquette, Clayton County; Dubuque, Dubuque County; near Fayette, Fayette County; Floyd, Floyd County; near Iowa City, Johnson County; near Stone City and Anamosa, Jones County; and near Cedar Rapids, Linn County. A lime plant is operated intermittently at Hurstville, Jackson County, where riprap and some crushed and ground limestone are also produced. A large cement plant is operated near Davenport, Scott County, using local raw materials. Concrete aggregate, road stone, agricultural limestone, and flux are also produced extensively in this county, particularly near Buffalo and Linwood. A large road-stone quarry is situated at Decorah, Winneshiek County.

Limestone industries of some magnitude are located in central Iowa. Large quarries for production of concrete aggregate, road stone, ballast, and agricultural limestone are in operation at Alden, Hardin County; Legrand, eastern Marshall County; and Earlham, Madison County. Quarries at Earlham also supply limestone and shale for cement manufacture.

Two large cement plants are active at Valley Junction near Des Moines, Polk County, but neither obtains its limestone near by. One plant derives its supply from Earlham, Madison County, and the other, which has obtained stone from Mississippian beds near Gilmore City in Pocahontas County, later acquired a deposit near Winterset, Madison County. Two of the largest cement plants in the State are at Mason City, Cerro Gordo County, in northern Iowa. Both limestone and shale are obtained from near-by quarries in Upper Devonian strata, which also supply stone for aggregate and other uses. Pure limestone from Osage, Mitchell County, is supplied at times to sugar factories. A large cement plant at Gilmore City, Pocahontas County, uses local raw materials. Aside from this plant and some small quarries, limestone is utilized to a very limited extent in western Iowa. Quarries in the extreme southeast at Keokuk, Lee County, and Douds, Van Buren County, produce concrete aggregate, road stone, agricultural limestone, and flux.

Kansas.—Commercial limestones of Mississippian, Pennsylvanian, and Permian age are confined to the eastern third of Kansas. Cretaceous rocks in the central and western areas contain limestones, but little economic use has been found for them. The lower Niobrara member of the Cretaceous of western Kansas contains large reserves of chalk that

may in future find an important place in industry. Cement manufacture is important in eastern Kansas because the Pennsylvanian (Upper Carboniferous) formation, which appears in the counties of the three eastern tiers and part of the fourth tier, contains high-grade limestones and shales and because markets and transportation routes are convenient. Seven or eight plants are normally in operation, with a total annual production of nearly 7,000,000 barrels. The total annual production of crushed limestone for concrete aggregate, road construction, and railroad ballast normally is about $1,000,000 at the quarries.

Except for one plant at Bonner Springs, Wyandotte County, not far from Kansas City the cement industry is centered in the southeastern corner of the State. Allen County has three plants, at Iola, Humboldt, and Mildred, respectively. Other plants are at Chanute, Neosho County; Independence, Montgomery County; Fredonia, Wilson County; and Fort Scott, Bourbon County. The only natural cement plant in Kansas is at Fort Scott, and lime was manufactured here many years ago.

Crushed limestone for concrete aggregate, road building, railroad ballast, and agricultural uses and to a limited extent for other applications is produced in the southeastern district, principally at Fort Scott, Bourbon County; Humboldt and Moran, Allen County; Parsons, Labette County; Moline, Elk County; Eldorado, Butler County; and Galena, Cherokee County. In the northeastern area crushed-stone products are obtained from several quarries near Kansas City, Wyandotte County; at Atchison, Atchison County; near Topeka, Shawnee County; at Fort Riley, Geary County; and in Douglas and Johnson Counties. In the east-central part of the State a small output has been recorded from Marion, Linn, and Osage Counties and from more extensive quarries near Ottawa, Franklin County; and Garnett, Anderson County. Atchison, Doniphan, and to a less extent Anderson, Cowley, Franklin, Shawnee and Wyandotte Counties produce riprap, mainly for river and harbor work.

Kentucky.—Limestones are widespread in Kentucky, as in most of the Middle West States. Pennsylvanian (Upper Carboniferous) limestones appear in many eastern and southeastern counties, as well as in the northwest, but most of them are too thin or impure to have great commercial importance. Mississippian (Lower Carboniferous) limestones occur in eastern, central, and western Kentucky, while Ordovician (Cincinnatian, Trenton, and Stones River) formations outcrop prominently in the north-central region. As high-quality rocks are available to transportation lines in many localities the crushed-stone industry is large and widespread, with well-equipped, active quarries in more than 30 counties distributed in various parts of the State. Crushed stone sold for concrete aggregate, road stone, and ballast was valued in 1929 at more than $2,250,000 and in 1937 at about $2,555,000 at the quarries.

A large proportion was limestone. Although low-magnesian limestones are plentiful there is only one cement plant in the State. Two large lime plants are normally in operation. Aside from lime and cement, the chief marketed commodities are concrete aggregate, road materials, railroad ballast, and agricultural limestone, with a smaller output of riprap, flux, screenings, and pulverized products.

Greatest activity is in the north-central counties, most of which have within their boundaries one or more quarries for the production of crushed stone. The one cement plant at Kosmosdale, in southwestern Jefferson County, obtains its supply of limestone 30 miles to the west, in Meade County. The stone is brought to the plant by barges on the Ohio River. Stone for concrete aggregate, road construction, railroad ballast, and agriculture, and to a small extent for other uses, is obtained from a group of six or seven quarries near Louisville, Jefferson County; and from large quarries near Clermont, Bullitt County; Tyrone, Anderson County; Frankfort, Franklin County; and Highbridge, Jessamine County. Less extensive operations are reported from Nelson, Spencer, Oldham, Henry, Owen, Scott, Fayette, Clark, Bourbon, Harrison, Kenton, Campbell, and Fleming Counties. A considerable tonnage of riprap is obtained at times in Campbell County.

Quarries for the production of crushed stone are established in central Kentucky, notably at Danville and Perryville, Boyle County; at Trimble, Pulaski County; Jackson and Lincoln Counties; and at Withers, Mount Vernon, and Sparks Quarry, Rockcastle County. The largest, most continuously operated lime plant in Kentucky is at Pine Hill, Rockcastle county. Its products are used in the chemical, metallurgical, and building industries, and for agriculture. A smaller lime plant was in operation a few years ago at Campbellsville, Taylor County.

Crushed and broken limestone is produced extensively in western Kentucky. Large quantities of riprap for use along the Ohio River are quarried at Smithland, Livingston County. Quarries for production of crushed limestone operate more or less continuously at Stephensburg and Upton, Hardin County; in Larue County; at Irvington, Breckenridge County; Russellville, Logan County; in Warren and Barren Counties; at Hopkinsville, Christian County; Cerulean, Trigg County; Princeton, Caldwell County; and in Crittenden County.

Supplies of roadstone and ballast are available also in eastern Kentucky. Well-equipped quarries produce a large tonnage of crushed limestone at Olive Hill, Lawton, and Carter, Carter County, and at Yellow Rock, Lee County.

Louisiana.—Commercial limestones of Louisiana are limited to two occurrences—one in Winn and the other in Evangeline Parish. Each is part of the cap rock of a salt dome and is of indeterminate age. The most important is the Winn Parish outcrop, about 3 miles west of the

town of Winnfield. The rock is a blue or in places a black and white banded crystalline limestone, which has been used for lime burning, concrete aggregate, railroad ballast, riprap, agricultural limestone, and furnace flux. Since 1929 it has been utilized extensively for road building and railroad ballast. A massive calcareous sandstone, probably of Middle Eocene age, occurring near Coochie Brake in this county has been described in literature as limestone. It has been used to a very limited extent.

Two small outcrops of fine-grained, dark gray limestone, containing small amounts of asphalt in pores and crevices, occur 7 miles southwest of the village of Bayou Chicot, Evangeline Parish. They are parts of the cap rock of the Pine Prairie salt dome. The rock was used for the manufacture of lime before the Civil War and again for this purpose in 1934.

It is reported that limestone concretions of Tertiary age have been used for the manufacture of crushed stone at Shreveport and for lime burning near Natchitoches. A large cement plant at New Orleans uses limestone and shale, which are quarried in Alabama and brought to the plant by water.

Maine.—The most important limestone deposits of Maine are in the ancient Taconic series of uncertain age near Rockland, Knox County. They are surrounded by schists and other siliceous rocks and have been so tilted from their original horizontal position that in some places the bedding is practically vertical. As a result of metamorphism they are all highly crystalline. Both high-magnesian and high-calcium rocks are available. Resources of commercial stone are large and for many years have supplied raw materials for an extensive lime industry. Seven lime plants are, or have recently been, in operation in the district which includes Rockland, Rockport, Union, and Thomaston. A large cement plant at the latter town utilizes stone from this belt. A limestone outcrop near Caribou, Aroostook County, in the northern part of Maine has been utilized for manufacture of lime.

Crushed-limestone production in Maine is confined to a limited output in the Rockland area of concrete aggregate, railroad ballast, agricultural limestone and stone for paper mills. Numerous limestone areas appear in other parts of the State, but lack of markets and scarcity of transportation lines have discouraged development.

Maryland.—Maryland is well-supplied with limestones of many geologic ages from pre-Cambrian to Carboniferous. The most ancient are the crystalline varieties, probably of pre-Cambrian age, that outcrop prominently in Carroll, Baltimore, and Howard Counties and less extensively in Frederick County. Some of them, the Cockeysville marble, for example, are magnesian, while others, such as those at Texas and Union Bridge, are of the high-calcium type. Limestones of Cambrian age—the Shady dolomite and Elbrook limestone—outcrop chiefly north-

east of Harpers Ferry; and the Stones River and Beekmantown limestones of Ordovician age outcrop across Washington County, through, and west of Hagerstown; and in Frederick County, near Frederick. Silurian (Cayuga) argillaceous limestones occur in thin, persistent beds in Allegany County and the western part of Washington County. Devonian (Helderberg) limestone occurs above the Silurian in the same general locations. Mississippian (Greenbrier) limestone outcrops only in Allegany and Garrett Counties. Following is a brief review of the crushed-limestone industries of Maryland, beginning with the eastern, or oldest, formations.

A verde antique marble quarry is worked at Cardiff, northern Harford County, and large tonnages of terrazzo chips, with smaller quantities of aggregate and ballast, are produced as by-products. Ground waste stone is used also for the manufacture of cement blocks.

The crystalline calcareous rocks of Baltimore County are utilized as sources of marble, lime, and crushed stone. Large marble quarries have been worked for many years at Cockeysville, and some of the waste dolomitic marble is crushed and ground for poultry grit and agricultural limestone. Lime is manufactured at Texas, and fluxing limestone, stucco, and filter stone are obtained from several small quarries. Union Bridge, Carroll County, is the center of a large cement industry, and lime has been produced at Union Bridge and Westminster. Production of crushed stone also is reported from this county.

Frederick County limestones have been utilized in many places. Large lime plants are operated at Lime Kiln, Grove, Le Gore, and Woodsboro, with smaller production at times near Thurmont and Buckeystown. Quarries for production of concrete aggregate and road stone are operated near Emmitsburg, Frederick, and Thurmont. Washington County is an important source of limestone products. Cement is manufactured in large quantities at Security near Hagerstown, and both lime and crushed stone are produced at Cavetown. Large quarries for crushed-stone production are located near Hagerstown and Hancock.

In the extreme western section limestone is utilized chiefly as road stone. The principal quarries are at Oakland, Garrett County; and Cumberland and Mount Savage, Allegany County.

Massachusetts.—The calcareous rocks of Massachusetts consist chiefly of Cambrian and Ordovician high-calcium and dolomitic marbles, which are confined principally to Berkshire County at the western edge of the State. High-calcium crystalline rocks are confined to the northwestern part of the county; nearly all of those in the central and southern areas are dolomitic. Limestone quarries of commercial importance are confined to Berkshire County.

Lime is a very important mineral product in Massachusetts, the State ranking fifth in value of output in 1929 and fourth in 1932. Normally

about eight plants, some large and provided with the most modern equipment, are in operation. The chief centers of lime manufacture are Adams, Farnams, Pittsfield, West Stockbridge, Lee, and Great Barrington. Fluxing and agricultural limestone, stucco, and poultry grit are produced from dolomite beds at Ashley Falls. Stone for furnace flux, agricultural use, and paper manufacture is quarried at Pittsfield. Operations at West Stockbridge produce a large tonnage of agricultural limestone, and this product, with fluxing stone, is obtained from quarries at Lee. It is noteworthy that practically no calcareous rock is quarried for concrete aggregate, road stone, or ballast in Massachusetts, as such needs are supplied from trap and granite quarries.

Michigan. *Geology of Limestones and Extent of Industry.*—The chief commercial limestones and marls of Michigan are of Devonian, Carboniferous, and Quaternary ages. Most pre-Cambrian crystalline limestones and dolomites which occur in the iron-ore districts in the western half of the northern peninsula are too impure to be of economic importance, though some relatively pure deposits are used in Dickinson County.

In the eastern part of the northern peninsula Ordovician limestones, under the general name "Trenton," occur in Menominee, Delta, and Schoolcraft Counties and extend eastward through the center of the peninsula to St. Marys River. The rock, much of which is argillaceous, is high in calcium in the upper part and magnesian in the lower part. Its thickness ranges from 250 feet on Green Bay to 100 feet on St. Marys River. Silurian (chiefly Niagara) limestone forms a belt 10 to 15 miles wide from Garden Peninsula on the east side of Green Bay eastward along the north shore of Lake Michigan and Lake Huron to the east end of Drummond Island. Great thicknesses of high-grade rock are available.

In the southern peninsula Bass Island (Upper Silurian) impure dolomite occurs in heavy beds in Monroe County. Dundee limestone of Lower Devonian age occurs in a belt 2 to 9 miles wide running northeast across Lenawee, Monroe, and Wayne Counties in southeastern Michigan. It occurs also at the extreme north of the southern peninsula on Mackinac and near-by islands and in adjacent parts of the northern peninsula. Very thick deposits of Dundee limestone occur in a belt from a point about 6 miles west of Rogers, Presque Isle County, southeast to False Presque Isle Island. The largest area is near Rogers, where there are apparently several hundred million tons of high-calcium limestone, the upper 60 to 90 feet averaging from 97 to over 98 per cent calcium carbonate.

The Traverse formation, also of Devonian age, lies above the Dundee. It forms a belt 2 to 3 miles wide across southeastern Michigan and another belt 12 to 15 miles wide around the northern end of the southern peninsula from Alpena on Lake Huron to Little Traverse Bay on Lake Michigan. From this point it forms a much narrower belt southwestward to Frank-

fort, Benzie County. This formation is not exposed in southeastern Michigan but occurs in extensive outcrops in many parts of the northern belt, where it ranges from 600 to 800 feet in thickness. In this belt the reserves are practically inexhaustible. The Dundee and Traverse formations of the northern belt may be regarded as more productive of limestone commodities than any other area of equal size in the United States.

A third important limestone formation,—the Grand Rapids of Carboniferous age—consists of the Bayport limestone at the top and the Michigan series of shale, limestone, and gypsum at the bottom. Important outcrops occur near Bayport and Pigeon, Huron County, on the east side of Saginaw Bay; on the Charity Islands in Saginaw Bay; at several places in Arenac County; Bellevue in Eaton County; and near Portage River 5 or 6 miles north of Jackson. Both magnesian and high-calcium beds occur in the Bayport, and, although in places it is sandy and cherty, the purer beds range from 92 to over 96 per cent total carbonates.

In addition to the above massive limestones, Quaternary marl deposits abound throughout the southern peninsula. Most of them are too small for development, except as sources of agricultural limestone. They have been widely used for cement manufacture, but this consumption has greatly diminished. Some marls are fairly pure, although they rarely contain more than 95 per cent total carbonates.

Limestone and its products constitute an important part of the mineral wealth of Michigan, where sales of limestone, cement, and lime in 1929 were valued at more than $28,000,000. The value of these products in 1937 was more than $16,400,000. It normally ranks third or fourth among all the States as a producer of cement and limestone.

Cement Industry.—In normal times 14 to 16 cement plants are in operation. The present situation differs widely from that 15 or 20 years ago, when a large percentage of the cement production was from marl plants. Because of the shortage of raw materials, increasing cost of transporting marl from more and more distant points, low plant output, obsolescence of plants, and difficulty of winter operation, a change to other sources of raw material has taken place. Only about three marl plants are now active.

The first group of plants considered comprises those that now use marl and those that used it originally. Cement mills at Coldwater and Quincy, Branch County, and at Fenton, Genesee County, still use this material. A plant at Cement City, northwestern Lenawee County, originally used it as the chief raw material; later a mixture of marl and limestone was employed, and still later limestone shipped from a distance replaced marl entirely. A cement mill at Chelsea, Washtenaw County, used marl several years. This source of supply became unsatisfactory, and stone shipped to Detroit from an upper lake port was brought to Chelsea by rail. The plant was abandoned later. A mill at Newaygo,

Newaygo County, at first employed marl but now uses limestone shipped from Petoskey.

Only three cement plants in Michigan use local supplies of hard rock. Mills at Alpena, Alpena County, and at Petoskey, Emmet County, utilize the Traverse limestone, and a plant at Bellevue, southwestern Eaton County, uses Carboniferous rock which occurs near by.

An interesting trend in the Michigan cement industry has resulted from the enormous growth in production of limestone at lake ports in Schoolcraft, Presque Isle, Emmet, and Alpena Counties because of facilities for low-cost shipment. Large cement mills at Port Huron, St. Clair County; Detroit, Wayne County; and Bay City, Bay County; in addition to the Newaygo plant mentioned above, obtain most of their raw materials from these northern lake ports.

A cement mill at Dearborn, Wayne County, uses furnace slag and limestone screenings shipped from the northern quarries, and one at Wyandotte in the same county uses in part calcium carbonate formed as a by-product of alkali manufacture. The latter plant is the only one of its kind in America.

Lime Industry.—When economic conditions are normal six to eight lime plants operate in Michigan, all of them in the northern part of the State. Several plants are located in Charlevoix and Emmet Counties in the region surrounding Petoskey. The largest production is at Menominee, Menominee County, the stone being shipped by water from Rogers City. Other large plants are situated near Manistique, Schoolcraft County; and at Afton, Cheboygan County. Large quantities of lime are burned at Sault Ste. Marie in the manufacture of calcium carbide.

Raw-limestone Industry.—The extensive deposits of high-grade limestone close to deep water, the development of low-cost mass production, and the invention of ships that unload automatically have effected phenomenal development of large quarries near the north end of the lower peninsula and on the north side of Lake Michigan. The movement of limestone from Rogers City, Alpena, and Rockport on the lower peninsula and Port Inland on the upper peninsula, to various points on the lower lakes is comparable with the enormous shipments of iron ore from Great Lakes ports farther north and west. The largest and most completely equipped limestone quarry in the world is at Rogers City, Presque Isle County. The Dundee limestone is worked in two benches, each about 55 feet high, and the quarry face is about 3 miles long. When the author visited the quarry in 1927 electric shovels with 10-ton dippers were employed for loading, and 16 trains were required to carry rock to the crusher. The most modern methods of washing, screening, storing, and loading from storage are used. Many thousands, even millions, of tons of limestone are shipped from these ports to iron and steel furnaces; to alkali, carbide, and other chemical works; and to cement and lime

plants at various lake ports. Large quantities of cement and lime are manufactured in other States in plants that use Michigan limestone as raw material. Smaller quantities of stone are shipped to various ports for glass manufacture, agricultural use, and filler in asphalt and other products.

In Alpena County large quarries have been in operation at Alpena and Rockport for many years, and another began operation at Alpena in September 1931. Stone from Alpena is shipped to Wyandotte, Mich., and to Fairport, Ohio, for alkali manufacture, and the fines are made into Portland cement at Alpena and Wyandotte. The stone from Rockport is used chiefly for furnace flux and concrete aggregate.

Stone quarried in the Petoskey district is used not only for the manufacture of cement and lime, but also for furnace flux and for supplying sugar mills, and stone for the latter use is also obtained at Afton, Cheboygan County. At Bay Port, Huron County, a large quarry is operated to produce road stone and aggregate, with a smaller output of furnace flux and riprap.

Limestone is quarried at several points on the northern peninsula for a variety of uses in addition to the manufacture of lime. At the Fiborn and Ozark quarries in Mackinac County not far from Trout Lake, large quantities of metallurgical stone are produced, with smaller amounts for road construction, concrete aggregate, and railroad ballast. The Ozark quarry produces dolomite for refractory use. At Manistique, Schoolcraft County, stone for paper mills is the chief quarry product, aside from lime. A very large limestone operation at Calspar north of Hunts Spur is connected by a standard-gage electric railway 7 miles long to a large modern crushing plant and harbor at Port Inland, on Lake Michigan about 15 miles east of Manistique. Regular operation began in the spring of 1930. Road stone and concrete aggregate are produced at Wells and Gladstone, Delta County. At Randville and Felch, Dickinson County, special products are prepared for use in the manufacture of cast stone and paints.

Large quarries are in operation also in southeastern Michigan. Many thousand tons of road material, concrete aggregate, railroad ballast, and agricultural limestone are quarried at Monroe, Monroe County. At Sibley, Wayne County, a high-calcium stone is quarried, chiefly to supply alkali works, although there is also a substantial production of road stone, concrete aggregate, furnace flux, agricultural limestone, and asphalt filler.

Minnesota.—Commercial limestones, all of Paleozoic age, occur only in southeastern Minnesota. The oldest of them, the St. Lawrence, is a sandy, buff rock, of Cambrian age, which outcrops near Judson and St. Lawrence Siding on the Minnesota River and at many points along the Mississippi bluffs from Red Wing to the Iowa line. The chief commercial limestones are of Ordovician age and include the Oneota, Shakopee,

Platteville, and Galena formations. The Oneota dolomite, consisting of heavy gray or buff beds 75 to 200 feet thick, occurs prominently at Kasota and Mankato and almost continuously along the Mississippi River and its tributaries from Red Wing to the southeastern corner of the State. The Shakopee dolomite, which is 25 to 75 feet thick, lies above the Oneota. It outcrops along the Minnesota River at Shakopee and on the bluffs of the Mississippi River between St. Paul and Hastings.

The bluish or buff Platteville limestone, which is 12 to 30 feet thick outcrops prominently along the Mississippi River in Minneapolis and St. Paul and caps many hills in the southeastern counties. Important outcrops of Galena occur only in Dodge, Mower, and Fillmore Counties, where they supply quarry rock of good quality. Devonian limestones appear only in Mower, Fillmore, and Faribault Counties. Quaternary marls are plentiful.

Most Minnesota limestones are dolomitic, and many are nearly pure dolomites. Low-magnesian limestones occur only in the Platteville, Galena, and Devonian formations of the southeastern counties and possibly in the Cretaceous near New Ulm, Brown County.

The limestone industry of Minnesota is comparatively small; in fact, the annual value of the stone and its primary products other than building stone totals less than one half million dollars. Since the State has abundant supplies of gravel, with trap rock and granite available in certain localities, very little limestone is used on Minnesota highways.

Few supplies of low-magnesian limestones in locations advantageous for portland cement manufacture have yet been found, and no portland cement has been made from local stone. Natural cement is manufactured at Mankato, Blue Earth County, and near Austin, Mower County. At Duluth, St. Louis County, portland cement is manufactured in a large mill supplied with raw materials which comprise furnace slag from the iron furnaces at Duluth and limestone shipped from a Michigan lake port. The largest lime plant in the State is at Duluth, and its supply of stone is also obtained by water from Michigan. Lime is manufactured from native stone at Mankato, Blue Earth County, and Le Roy, Mower County.

Quarries producing crushed and broken limestone are confined to that section of the State lying south and southeast of Minneapolis. Quarries near Minneapolis, Hennepin County, supply considerable quantities of road stone and concrete aggregate for use in that populous center, as well as a small amount of ground limestone for agriculture and asphalt filler. Similar products are obtained from quarries near St. Paul, Ramsey County. Riprap for use along the Mississippi River is sold as a by-product of a marble industry at Kasota, Le Sueur County, and derived also from quarries at Mankato. Road stone and concrete aggregate are obtained in the latter region and also at various points in Olmsted and

Fillmore Counties. Quarries on the river bluffs near Winona, Winona County, supply road stone, concrete aggregate, agricultural limestone and terrazzo chips. Small quantities of riprap are produced in Houston County in the extreme southeast. Marl is used extensively on roads in Crow Wing County and for liming soils in Stearns, Sherburne, and Wright Counties. A small amount of crushed limestone for aggregate is reported from Goodhue County, and riprap, flux and aggregate from Rice County.

Mississippi.—The Mississippi limestones are of Devonian, Carboniferous, Cretaceous, Eocene, Oligocene, and Tertiary age. Siliceous Devonian limestones and some fairly pure Mississippian (Lower Carboniferous) calcareous rocks are exposed in Itawamba and Tishomingo Counties in the northeast, but transportation facilities are inadequate. Selma Chalk, of Cretaceous age, outcrops in a zone 10 to 30 miles wide, passing southward from Alcorn County at the Tennessee line to Noxubee County, where it turns eastward into Alabama. It is 250 to 900 feet thick, and the best of it contains 70 to 84 per cent total carbonates. By careful selection chalk of good quality might be obtained. The Ripley limestone, of Upper Cretaceous age, and the Midway (Eocene) fossiliferous limestone occupy small areas west of the Selma Chalk. A belt of Vicksburg (Tertiary) limestone crosses the State from Waynesboro to Vicksburg. The formation, consisting largely of alternating beds of limestone and marl, is not well-suited for the production of crushed stone or lime, although the combination might not be unsatisfactory for the manufacture of cement.

No cement or lime and very little crushed stone are produced in Mississippi. The principal requirements for road work, concrete aggregate, and railroad ballast are supplied from numerous gravel banks. The Selma Chalk is quarried near Okolona, Chickasaw County, and the Vicksburg limestone is now or has been quarried near Vicksburg, Warren County; near Brandon, Rankin County; and on Limestone Creek, 3 or 4 miles northwest of Waynesboro, Wayne County. An important use of the product is for liming the land.

Missouri.—Cambrian dolomite or magnesian limestone covers a large part of southeastern Missouri, except the corner counties, where the covering is Tertiary clay, gravel, and sand. Ordovician limestones outcrop prominently near the Mississippi River northward from Cape Girardeau to the northern part of Jefferson County. They cover western St. Louis County and northern Franklin County and appear in St. Charles, Warren, Montgomery, and Callaway Counties on the north side of the Missouri River. They are exposed again near the Mississippi River farther north in Lincoln, Pike, Ralls, and Marion Counties. Most of them are low in magnesium, and many of the deposits are of a high degree of purity.

Mississippian (Lower Carboniferous) limestone, much of which is high in calcium and contains a low percentage of impurities, covers extensive areas along the Mississippi and Missouri Rivers and in the southwestern counties. It is used widely for lime and cement manufacture and as crushed stone at various points along the Mississippi River, notably in Ste. Genevieve, St. Louis, St. Charles, Lincoln, Marion, Lewis, and Clark Counties. In the southwest it is utilized most extensively in Greene and Jasper Counties. Almost all northern and western Missouri is covered by the Pennsylvanian (Upper Carboniferous) series, which consists chiefly of shales and sandstones but contains some beds of limestone, which are utilized principally in Clay and Jackson Counties.

The manufacture of cement and lime and the quarrying of limestone for use in crushed and broken form are important industries in Missouri; the normal annual sales value of such products is approximately $19,000,000. In 1929 the value of cement sold exceeded $11,500,000, and the marketed value of lime at the plants exceeded $2,300,000. In 1937 these totals were $7,041,016 and $2,326,928, respectively. The State ranks third as a producer of lime; it is exceeded only by Ohio and Pennsylvania. Missouri leads all other States in production of riprap, used for shore protection along the Missouri and Mississippi Rivers.

Normally five large cement plants at widely separated points are in operation. A plant at Hannibal, Marion County, in the northeast, and two plants near St. Louis utilize Mississippian limestone. A cement mill at Independence, Jackson County, near the western edge of the State, uses Pennsylvanian limestone, and one near Cape Girardeau in the southeast employs Ordovician rock.

Thirteen to 18 lime plants operate in Missouri under normal business conditions. The most productive district is at Ste. Genevieve, Mosher, Brickeys, and nearby territory, Ste. Genevieve County, where large, well-equipped plants produce high-calcium lime from the Spergen formation of Mississippian age and the Kimmswick limestone of Ordovician age. Lime plants are operated also at Centaur and Glencoe, St. Louis County, and at Byers and Glen Park, Jefferson County.

A second important lime-producing center is in the southwest, where high-grade Mississippian limestone is available. Large plants are situated at Ash Grove, Galloway, and Springfield, Greene County, and smaller plants at Pierce City, Lawrence County, and near Osceola, St. Clair County. Burlington limestone, of Mississippian age, is utilized for burning lime in a third district at Hannibal, Marion County.

Quarries for the production of crushed and broken limestone are widely scattered throughout the State, the east-central district around St. Louis and west-central district in the neighborhood of Kansas City being the most productive. Numerous quarries in and about the city of St. Louis provide many thousand tons of riprap for river work, and also

crushed limestone for street and highway construction and for concrete aggregate. Quarries at Clayton, Florrisant, Glencoe, Jefferson Barracks, Koch, Vigus, University City, and other small towns in St. Louis County also contribute to the demands of this populous center. Large quarries at Weldon Springs, St. Charles County, supply railway ballast, road stone, agricultural limestone, and riprap, the last commodity being produced also at Bernheimer, Warren County. At Elsberry, Lincoln County, limestone is quarried for glass factories, agricultural use, and filler and whiting substitute. Auxvasse and Cedar City, Callaway County, and Berger, Franklin County, are important centers for production of riprap. Large quantities of riprap are produced at Louisiana, Pike County; Columbia and other points in Boone County; and in Moniteau, Montgomery, and Ralls Counties. Dolomite for refractory use is quarried near Bonne Terre, St. Francois County.

Quarries in Ste. Genevieve County produce stone for riprap, concrete aggregate, and road building, also finely ground stone for coal-mine dusting, paint, asphalt filler, and other industrial uses. At Cape Girardeau, Cape Girardeau County, in southeastern Missouri large quantities of road stone, concrete aggregate, and agricultural limestone, and a small amount of riprap are produced, while at Neely's Landing in the same county riprap is the leading product.

Moderate supplies of road stone and agricultural limestone are obtained at White Bear and Hannibal, Marion County, in northeastern Missouri. Stone from these quarries is used also for poultry grit, asphalt filler, mineral-food mixtures, and whiting substitute. Riprap and crushed stone are produced in Lewis and Clark Counties. The largest operations in central Missouri are for production of riprap, notably at Osage City, Cole County; Blackwater and near Arrow Rock, Cooper County; Wellington, Lafayette County; Glasgow, Howard County· and Slater, Saline County. A substantial production of road stone, concrete aggregate, railroad ballast, and agricultural limestone is also obtained at Blackwater.

Western Missouri is well-supplied with limestone quarries. In Greene County the important lime industry of Ash Grove and Galloway and the building-stone industry of Phenix are supplemented by a moderate production of crushed stone and agricultural limestone. Road stone concrete aggregate, and agricultural limestone are produced in large quantities from several quarries near Springfield. At Carthage, Jasper County, both crushed stone and ground products are made, the latter including poultry grit, terrazzo and roofing chips, and asphalt filler. Carthage stone is also supplied to glass and sugar factories and to metallurgical works. Some of the largest quarries in the State and at least a dozen smaller ones are active in and near Kansas City and Independence, Jackson County. Like the quarries around St. Louis their

principal activity is the production of road and street-paving material and concrete aggregate for use in public works and building construction. Riprap is produced in smaller amount, and agricultural limestone and other ground products are also marketed. Near-by quarries at Birmingham, Smithville, Excelsior Springs, Missouri City, and South Liberty, Clay County; St. Joseph, Buchanan County, and at Amazonia, Andrew County, are sources of similar products.

Montana.—The most valuable limestones of Montana are confined to the western part of the State. They occur in massive beds flanking the mountain ranges from Red Lodge in Carbon County through Livingston in Park County northwest to the principal mountain ranges west of Great Falls in Lewis and Clark and Powell Counties. In places the beds are nearly vertical. The purest limestones are of Mississippian (Lower Carboniferous) age; but impure limestones (dolomitic, siliceous, and argillaceous) of Jurassic, Pennsylvanian, Devonian, Cambrian, and pre-Cambrian Age are widespread and of great thickness. Cretaceous rocks, outcropping in many places throughout the eastern two thirds of the State, contain lenses and concretions of limestone that have been used locally for lime burning.

Two cement and two lime plants have recently been in operation. The chief production of crushed limestone is for smelter flux; road material and concrete aggregate are next in importance, while somewhat smaller amounts are quarried for riprap and for supplying sugar refineries.

Jefferson is usually a productive county. The quarry centers are at the northern end near East Helena and in the south at Limespur where interesting underground methods are used. The stone is of exceptional purity, much of it exceeding 98 per cent total carbonates; on this account the larger part of the output is used for flux or for sugar manufacture, though some of it is used for road stone and concrete aggregate.

Pure, high-calcium limestone quarried near Sappington, Gallatin County, is used for sugar refining, while the more siliceous rock at Trident near Three Forks is quarried for cement manufacture. Lime is manufactured at Lost Creek 7 miles west of Anaconda in Deerlodge County, and a considerable quantity of fluxing stone, with a minor output of crushed stone, is also obtained in this county. Lime used chiefly for metallurgical purposes is manufactured near Elliston, Powell County. Stone for sugar manufacture is quarried at Drummond, Granite County, and for both sugar refineries and for use in crushed form in Cascade County. The only noteworthy riprap quarry in the State is in Musselshell County. Upper Paleozoic limestone is used for cement manufacture at Hanover, Fergus County. Calcite from veins occurring near Springdale, Park County, is utilized in stock and chicken food.

Nebraska.—Limestones of greatest economic value in Nebraska are the Pennsylvanian and Permian, of Carboniferous age, and the Niobrara,

of Cretaceous age. Pennsylvanian limestones outcrop chiefly in the southeastern counties—Sarpy, Cass, Lancaster, Otoe, Johnson, Nemaha, Pawnee, and Richardson. Available Permian limestones are confined chiefly to Gage County. The Niobrara formation is exposed most prominently along the Missouri River in northeastern Nebraska, and from Alma to Superior in the Republican Valley at the southern edge of the State. Representative analyses of this chalklike formation show a total carbonate content of 67 to 96 per cent. As a source of commercial chalk it has possibilities that have not yet been developed.

The limestone industries of Nebraska are relatively small and confined to southeastern counties; of these, Cass and Sarpy are the most productive. Pennsylvanian limestone is utilized at Louisville, Cass County, for cement manufacture and for production of concrete aggregate, road stone, riprap, railroad ballast, flux, and agricultural limestone. Most of the stone is obtained from underground mines. Riprap is quarried near Nehawka. At Weeping Water riprap and stone for poultry grit and for glass making are produced, with large amounts of pulverized limestone for use in rubber, putty, paint, and asphalt. Riprap, road stone, and concrete aggregate are produced north of Louisville in Sarpy County; and Permian limestone is, or has been, quarried for similar purposes at Blue Springs, Gage County. The Niobrara chalk formation is utilized for cement manufacture at Superior, Nuckolls County.

Nevada.—Limestones, chiefly of Carboniferous age, outcrop in various places in the eastern third of Nevada. Crystalline limestones are reported in Esmeralda and Elko Counties. Owing to difficulty of transportation and limited markets few quarries have been operated. Chief developments are in Clark County, where both high-calcium and magnesian limestones are available. High-calcium and dolomitic rocks are utilized extensively at Sloan; the chief products are limestone for sugar mills and open hearth furnaces, ground limestone, and a smaller quantity of crushed stone. Lime and crushed stone have been produced also at Jean. A small output in other counties is used locally only.

New Hampshire.—Very little limestone occurs in New Hampshire, and there has been no recent production. Occurrences are confined almost exclusively to the Helderberg (Devonian) formation of Grafton County. Crystalline limestones of variable composition were utilized many years ago for lime burning at various points, notably Littleton, Haverhill, and Lisbon.

New Jersey.—The Franklin limestone of pre-Cambrian age is the calcareous rock of greatest commercial importance in New Jersey. It is white, is coarsely granular and crystalline, and ranges in composition from nearly pure calcium carbonate to dolomite. It is utilized chiefly for cement manufacture in Sussex and Warren Counties. The Jacksonburg limestone of Ordovician age outcrops prominently in Warren County, and

its principal use is for the manufacture of cement. Although some of it runs as high as 95 per cent calcium carbonate it contains numerous shaly layers.

Limestones occur in various other formations, but the only one of present economic importance is the Kittatinny magnesian limestone of Cambrian and Ordovician age. It occurs in thick, highly foliated beds, which are most readily available for commercial use in Sussex, Warren, Somerset, and Hunterdon Counties.

Cement is the most important limestone product of New Jersey. Large mills are in operation at New Village and Vulcanite, Warren County, and until recent years it was manufactured also at Alpha near Vulcanite. The so-called cement rock is an argillaceous limestone which approaches the proper composition for a cement mixture as it occurs in nature.

In Sussex County a large quarry in the crystalline beds near Newton produces stone for a great variety of uses, including road stone, concrete aggregate, fluxing stone, agricultural limestone, poultry grit, and pulverized material for asphalt filler and various other applications. Fluxing stone for iron furnaces at Bethlehem, Pa., has been quarried at McAfee, but the quarry is now inactive. Limestone is obtained at times from quarries near Hamburg and Sparta. Lime plants were at one time operated at Hamburg and McAfee.

Dolomitic limestone occurring at Peapack, Somerset County, is used for lime burning and also for road stone, concrete aggregate, agricultural limestone, and asphalt filler. Similar stone for highway construction is quarried near Clinton, Hunterdon County.

New Mexico.—Limestones of Ordovician, Silurian, Carboniferous, and Cretaceous age occur in New Mexico; however, very little is known of their extent and quality. Inadequate transportation and restricted markets have discouraged developments. Aside from a small lime plant near Meadows, San Juan County, the only noteworthy activity is at Montezuma, San Miguel County, where lime, road stone, and concrete aggregate are produced.

New York. *General Geology and Production Centers of Limestone.*—Except for the southern counties along the Pennsylvania border limestones are distributed widely in New York and constitute the most important source of crushed stone. Crystalline limestones of pre-Cambrian age occur extensively on the west side of the Adirondacks in Lewis, Jefferson, and St. Lawrence Counties. Cambrian limestones and dolomites occur in Herkimer and Saratoga Counties and in a small area in the Champlain Valley. The Chazy limestone of Ordovician age outcrops at various points in the eastern Adirondacks from Saratoga County north to the Canadian boundary, attaining its maximum thickness in Clinton County. It is gray and finely crystalline and contains 95 per cent or more calcium carbonate.

The Mohawkian formation (including Trenton, Black River, and Lowville), also of Ordovician age, is very important commercially. One belt beginning in the Champlain Valley near Whitehall extends through northern Washington County to Glens Falls in southern Warren County and continues into Saratoga County. Another belt begins in the Mohawk Valley and extends with gradually increasing width northwest through Oneida, Lewis, and Jefferson Counties to the St. Lawrence River. The formation occurs also along the lower Hudson River near Poughkeepsie. The Mohawkian limestone is gray to almost black and is generally pure and low in magnesia. It is used for cement and lime manufacture and is crushed and pulverized for various purposes.

The Clinton, Lockport, and Guelph members of the Niagara group of Silurian age extend from Otsego County northwestward to Oneida Lake and westward through Rochester to the Niagara River. The Clinton, the most important member, is quite argillaceous in the eastern section but becomes purer to the west and occurs as a high-grade limestone in the Niagara district. It is important as a source of fluxing stone for the Buffalo smelters, although most of their supply is now obtained by water from Michigan lake ports. The Lockport limestone is quarried near Rochester. Cayugan limestone, also of Silurian age, occurs in Erie, Schoharie, Onondaga, and Ulster Counties. This formation is suitable for the manufacture of natural cement in Ulster and Erie Counties.

The Helderberg and Onondaga limestones of Devonian age are extensive and have great economic importance. The belt extends from Buffalo in Erie County eastward to Oneida County, and southeast to Albany County, where it curves south through Greene, Ulster, eastern Sullivan, and Orange Counties to the Delaware River. It is generally a bluish gray, massive limestone containing some chert. It is used widely as crushed stone and for cement and lime manufacture. The most extensive as well as the purest rocks occur in the central and southern areas of the belt.

The Tully limestone, also of Devonian age, occurs in a very irregular belt intersecting the Finger Lakes of central New York. It is thin, somewhat argillaceous, and best-adapted for crushed stone or for cement manufacture, but is suitable for lime manufacture in places. Quaternary marls occur extensively in central and eastern parts of the State. Newland[65] describes New York limestones in greater detail.

The principal centers of limestone production are in the Hudson River Valley, for the New York market; in Oneida, Madison, and Onondaga Counties, for the central New York markets; and in Monroe,

[65] Newland, D. H. The Mineral Resources of the State of New York. New York State Museum Bulls. 223, 224, 1919, pp. 255–272.

Genesee, and Erie Counties, for the demands of Buffalo, Rochester, and other western markets.

New York ranks second as a producer of crushed limestone, and it normally ranks fourth as a producer of cement. The total value at the plant of cement, lime, and limestone sold in the State in 1929 exceeded $30,000,000. It had dropped to about half that amount in 1932.

Cement Industry.—The most productive district is in the Hudson River Valley, where cement is now, or has recently been, manufactured at Cementon, Alsen, and Catskill, Greene County, and near Hudson, Columbia County, on the opposite side of the river. In eastern New York cement plants are also operated at Glens Falls, Warren County; and at Howes Cave, Schoharie County. There is a plant for the manufacture of natural cement at Rosendale, Ulster County. Jamesville, Onondaga County, and Portland Point, Tompkins County, are the productive areas of central New York. Cement requirements of the western part of the State are supplied principally from plants at Akron and at Buffalo, Erie County. Part of the limestone supplied to plants in this district is shipped by water from Michigan Lake ports.

Lime Industry.—Lime plants are operated in many parts of New York, but few are large. The largest eastern centers are at Chazy, Clinton County; at Glens Falls, Warren County; and at Dover Plains, Dutchess County. A few small plants operate in Washington, Fulton, and Ulster Counties. In the central area lime is manufactured at Jordanville, Herkimer County; and dead-burned dolomite is prepared for refractory uses at Natural Bridge, Jefferson County. A small output is reported from Seneca County. Lime plants are operated at Oakfield, Genesee County, and at Buffalo, Erie County, in western New York. The Buffalo plant is supplied with stone from Michigan.

Manufacture of Crushed and Ground Limestone.—Quarries for the manufacture of crushed-limestone products are most numerous in eastern New York. At Chazy and Plattsburg, Clinton County, in the northeastern corner of the State, limestone is quarried for flux, road stone, and concrete aggregate. Stone for the last-named uses is quarried at Glens Falls and other points in Warren and Washington Counties. Pure rock obtained at Bald Mountain in the latter county has been sold to paper mills. Other important quarries for production of concrete aggregate and road stone are operated at Saratoga Springs, Saratoga County; Mayfield, Fulton County; Cranesville, Montgomery County; Schoharie, Schoharie County; and Feura Bush, Ravena, and South Bethlehem, Albany County. In the southeastern counties several exceptionally large limestone quarries supply part of the enormous demands of the district in and about the city of New York. They are within easy distances of this extensive market and have the advantages of both rail and water transportation. There is a notable quarry at

Stoneco, Dutchess County, and a large new plant has recently been built at Clinton Point near by. Other large quarries are worked near Marlboro, Ulster County, on the opposite side of the Hudson River; near Newburgh, Orange County; Tomkins Cove, Rockland County; and Verplanck, Westchester County.

In north-central New York crushed limestone for aggregate, flux, paper mills, agriculture, and other uses is produced at Norwood, Ogdensburg, Gouverneur, and Richville, St. Lawrence County. Crushed limestone is also produced at Watertown, Jefferson County; Jordanville and Newport, Herkimer County; and Oriskany Falls and Prospect, Oneida County. Madison County is a producer of limestone for road work, concrete aggregate, agricultural uses, railroad ballast, and riprap. The chief quarry centers are Munnsville, Perryville, and Canastota. Exceptionally large quarries are worked in Onondaga County at Rock Cut and Jamesville, the major output of the latter locality being used for alkali manufacture. Auburn, Cayuga County, is another important quarry center.

The construction and industrial activities of western New York are well-supplied with limestone. Concrete aggregate, road stone, and ballast are quarried near Geneva, Ontario County. Exceptionally large, well-equipped plants produce crushed dolomite at Penfield and Rochester, Monroe County. Quarries at Le Roy and Stafford, Genesee County, and at Lockport and Gasport, Niagara County, supply fluxing stone for Buffalo furnaces in addition to large quantities of the usual crushed-stone products. The requirements of the Buffalo district are supplied mainly from quarries at Akron, Buffalo, and Cheektowaga, Erie County.

North Carolina.—The great post-Cambrian crystalline belt that provides extensive limestone resources in Alabama, Georgia, Tennessee, and Virginia passes west of North Carolina, therefore her resources are confined to relatively limited deposits of Cambrian and pre-Cambrian limestones, with Eocene, Miocene, and Quaternary shell rock and marls. Both high-calcium and magnesian limestones occur in many counties in the western section of the State, mostly in valleys, and are so covered with soil that careful surveying and prospecting are required to determine their extent and quality. Granite is so abundant in North Carolina that limestone is a relatively unimportant source of crushed stone. Production is confined almost exclusively to the southwestern counties. No cement is manufactured in the State.

Fletcher, in northern Henderson County, is the most active center of limestone production. Quarries in this locality supply materials for a substantial output of lime, crushed stone used chiefly for highway work, and a smaller amount of agricultural limestone. Crushed stone and agricultural limestone are produced at Ashford, McDowell County. Agricultural limestone and road stone are produced at times in Madison

County. Small quarries are operated in New Hanover County, and crushed marble is produced in Cherokee County. Coastal Plain marls of eastern North Carolina are used locally for soil improvement.

North Dakota.—The only limestone formation of North Dakota is the Niobrara, of Cretaceous age, a soft chalklike rock usually intermixed with clay. No cement, lime, and crushed stone are now produced in the State. A cement plant was operated some years ago in Cavalier County, but the rock was found to be too low in lime.

Ohio. *General Geology and Production Centers of Limestone.*—The oldest limestone formation of Ohio is the Trenton (Ordovician), which underlies much of the State but appears at the surface only in Clermont County. Cincinnatian limestone, also of Ordovician age, occurs in southwestern Ohio, in Hamilton County, and in several other counties to the east and north. There are numerous limestone layers, most of them limited to a foot or less in thickness and in general quite impure. Brassfield (Silurian) limestone somewhat irregular in composition occurs in southwestern Ohio, principally in Prebble, Montgomery, Miami, Clark, Greene, Clinton, Highland, and Adams Counties.

Niagara limestone, of Upper Silurian age, occurs prominently in western and northern Ohio. Exceedingly pure dolomites prevail in this formation and constitute much of the raw material for the most productive lime-manufacturing area in the country. The Lower Helderberg (Devonian) limestone of western and northern Ohio is chiefly dolomitic and supplements the Niagara as a source of raw material for the manufacture of magnesian lime. It is widely used also as crushed stone. Corniferous (Devonian) limestones occur in a belt in central Ohio extending from Pickaway County to Erie County and in a second belt in the northwest passing through Pauling, Henry, Wood, and Lucas Counties. Some of them are dolomitic, while others may have a magnesia content as low as 7 or 8 per cent. They are used for lime burning, for flux, and in crushed and pulverized form.

The Maxville (Lower Carboniferous) limestone is associated closely with the coal fields. It generally ranges from 80 to 90 per cent calcium carbonate, but most of it lies too far below the surface to have economic value. It outcrops or is easily available only in Perry, Muskingum, Vinton, Jackson, and Scioto Counties. The Putnam Hill (Upper Carboniferous) limestone lies in the western part of the coal fields. It is used for cement manufacture in Stark County, but in other places the bed usually is too thin.

In contrast to these two limestones, the Vanport or Ferriferous (Upper Carboniferous) limestone occupies a place of importance economically. It occurs in two areas, the northernmost of which is best developed in Mahoning County, where it is quarried for furnace flux. The southern area, which is the more outstanding, appears prominently in

Vinton, Jackson, Gallia, Lawrence, and Scioto Counties in southern Ohio. The beds range from 4 feet or less to a maximum of about 16 feet in thickness. The rock, which is relatively high in iron and low in magnesia and carries 80 to 90 per cent calcium carbonate, is used for cement manufacture in Lawrence County. In southeastern Ohio the Monongahela (Upper Carboniferous) limestone occurs quite extensively but is used to a limited extent only, as it is rarely pure, and most of it high in magnesium. Quaternary marls occur less extensively than in Michigan and Indiana.

Limestone is the raw material for a series of basic industries of vast importance in Ohio. With an output valued at $4,000,000 to $9,000,000 a year the State overtops all others by a wide margin as a producer of lime. Ohio usually ranks fifth or sixth in order in the manufacture of cement. The total sales value of cement, lime, and limestone (other than building stone) at the quarry, mine, or mill was approximately $33,000,000 in 1929 but had dropped to less than $25,000,000 in 1937.

Lime Industry.—Normally, 25 to 30 lime plants are in operation in Ohio. The most productive area in the State or, in fact, the whole country is the Toledo district, embracing Ottawa, Sandusky, Seneca, and Wood Counties. Unless otherwise specified, all the plants in this district produce high-magnesian lime that is particularly well-adapted for use in finishing coat plaster. Plants at Clay Center and Genoa, Ottawa County are among the largest in the world, that at the former locality having 53 shaft and 1 rotary kiln, and that at the latter having 40 shaft and 2 rotary kilns. Another large plant at Marblehead in this county produces high-calcium and low-magnesian limes. Gibsonburg and Woodville, Sandusky County, are also very large lime centers, three to four plants operating near each town. One of the Woodville plants has 53 shaft kilns. Dead-burned dolomite is manufactured at Bettsville and Maple Grove, and lime is made at Tiffin, Seneca County. Luckey, Wood County, is another source of supply.

A second district farther south reports substantial production of lime, although most of the plants are smaller than those in the district already mentioned. Lime plants are located at Carey, Wyandot County; Forest, Hardin County; Delaware, Delaware County; Columbus, Franklin County; and Cedarville, Greene County; while three plants operate near Springfield, Clark County. Low-magnesian lime is the product of Delaware and Franklin Counties.

A large quarry at Peebles, Adams County in southern Ohio provides dolomite which is manufactured into lime and dead-burned products at Kenova, West Virginia. In northeastern Ohio small plants near Bolivar, Stark County, and at Zoar, Tuscarawas County, burn agricultural lime for local use.

Cement Industry.—About 10 cement plants operate in widely scattered localities in Ohio. Along the northern border of the State there are plants at Toledo, Lucas County; at Castalia and Baybridge, Erie County; and at Painesville, Lake County. A plant at Middlebranch, Stark County, is supplied with Putnam Hill rock from a ledge about 12 feet thick overlying a thin seam of coal. A cement mill at Fultonham, Muskingum County, uses stone from an open quarry, but the supply is now supplemented from a recently opened underground mine. Two plants at Osborn, Greene County, utilize the Brassfield high-calcium limestone. Carboniferous limestones are used for cement manufacture in two localities in Lawrence County. At Superior a heavy capping of sandstone permits removal of Vanport limestone from underground drifts a short distance below the surface. At Ironton a vertical shaft penetrates the Maxville limestone at a depth of 450 feet, where an elaborate room-and-pillar mining system is followed.

Crushed- and Ground-limestone Industry.—Broken-, crushed-, and pulverized-limestone industries are extensive and consist of many widely distributed units. For convenience the productive counties are grouped by their geographic location. For the sake of brevity, no mention is made of places where production was small or quarries were inactive in recent years.

The first region described embraces a group of counties in northwestern Ohio. A small quarry is worked near Paulding, Paulding County; and several quarries operate near Cloverdale, Fort Jennings, Kalida, Ottawa, Rimer, and Pandora, Putnam County. A large quarry is operated near Findlay and smaller ones near Arlington, Findlay, Vanlue, and Williamstown, Hancock County. Chief centers of production in Wood County are North Baltimore and Portage, with smaller outputs at Bloomdale, Luckey, Rudolph, and other points. Almost the entire production of the quarries in the counties mentioned is used for road stone and concrete aggregate. There are very extensive developments at Waterville, Holland, Sylvania, and Whitehouse, Lucas County. The products are concrete aggregate, road stone, a substantial output of railway ballast, agricultural limestone, and stone for sugar mills. Quarries at Genoa, Clay Center, and Marblehead, Ottawa County, produce many thousand tons of crushed stone, and the last town also is an important center for the production of fluxing stone, agricultural limestone, and asphalt filler. Stone for refractory use and paper mills is produced in considerable quantities at Clay Center. Quarries near Bellevue and at Gibsonburg, Fremont, and Woodville, Sandusky County, produce very large quantities of crushed stone for road work and concrete aggregate. The pure dolomite is marketed extensively as furnace flux, refractory stone, and agricultural limestone and also is employed in glass factories. Stone is quarried extensively for similar purposes at Bascom, Bloomville,

and Maple Grove, Seneca County. Large fluxing-limestone quarries are operated on Kelleys Island, Erie County; and at Marblehead, Ottawa County. Equally large quarries at Sandusky produce road stone, concrete aggregate, ballast, and agricultural limestone. Part of the crushed-stone output of this northwestern district is produced in conjunction with the lime industry.

A second group of counties considered is in western and western-central Ohio. Large quarries near Delphos and at Middle Point, Van Wert County, produce about equal quantities of railroad ballast and stone for highways and concrete aggregate. Allen County has large quarries at Lima and Bluffton, with several smaller ones at Westminster and other points. Limestone obtained at Piqua, Miami County, is used for a variety of products, including concrete aggregate, road stone, fluxing stone, and poultry grit; in pulverized form it is used for agricultural limestone and filler for putty, asphalt, and other products. Other large quarry centers for railroad ballast, road stone, and concrete aggregate are at Ada, Dunkirk, Forest, and Kenton, Hardin County; Marion, Marion County; and Carey, Wyandot County. Crushed stone is produced at East Liberty, Belle Centre and Rushsylvania, Logan County, and east of West Mansfield, Union County. High-magnesian limestone is crushed for road work and agricultural use at Celina and Rockford, Mercer County. There are several smaller quarries in the latter counties and also near Lewisburg, Preble County; Centerville and Phillipsburg, Montgomery County; and Springfield, Clark County.

Important limestone industries are located in central and north-central Ohio. Quarries at Spore, Crawford County, and Delaware and Radnor, Delaware County, produce substantial quantities of road stone and aggregate. One of the largest quarries in the Middle West, at Columbus, Franklin County, produces crushed stone for ordinary purposes, and in addition large quantities of stone for furnace flux and alkali manufacture, smaller amounts for glass factories and chicken grit, and pulverized stone for agricultural use and as filler in asphalt and rubber.

In southwestern Ohio large quarries are operated at Melvin, Clinton County, and north of Greenfield, Fayette County. Crushed stone is produced also in Hamilton, Clermont, and Adams Counties. Limestone quarrying is relatively unimportant in the eastern half of Ohio. Production, except for local use, is confined chiefly to Fultonham, Muskingum County, where crushed stone is produced in conjunction with a large output of limestone for glass and cement manufacture, and to a quarry near Adena, Harrison County, the products of which are crushed stone and agricultural limestone.

Oklahoma.—The oldest limestone of Oklahoma is the Arbuckle, of Cambrian and Ordovician age, which occurs in two areas. The larger is in the Arbuckle Mountain district, including parts of Coal, Pontotoc,

Pittsburg, Atoka, Garvin, Murray, Carter, and Johnston Counties; the smaller area is in the Wichita Mountains, in Comanche and Kiowa Counties. The formation is 4,000 to nearly 8,000 feet thick, and the central part is dolomitic. It has been described in some detail in a recent report.[66] Heavy limestone beds, of Simpson (Ordovician) age, occurring prominently in the eastern and central parts of the Arbuckle Mountains and at the north end of the Criner Hills, have little commercial value at present. The Viola limestone, of Ordovician age and the Hunton, of Silurian and Devonian age, occurring in small areas adjacent to the Arbuckle formation, for the most part are low in magnesium but are inclined to be irregular in composition and somewhat siliceous. Mississippian (Lower Carboniferous) limestone, occurring in several southeastern counties, and Pennsylvanian (Upper Carboniferous), which is available in several counties in the northeastern section of the State, is suitable for the manufacture of cement and use as crushed stone.

The leading limestone industry of northeastern Oklahoma is the manufacture of cement at a large plant near Dewey, Washington County, where crushed stone for roads is also produced. Limestone is crushed chiefly for railroad ballast at Avant, Osage County. Large quarries for production of concrete aggregate, road stone, and smaller amounts of ballast, agricultural limestone, and asphalt filler are worked at Garnett, Sand Springs, and Price, Tulsa County. Lime has been produced at Sand Springs, in this county. Road stone is quarried in Rogers County and stone for glass factories in Adair County.

Southeastern Oklahoma likewise has one large cement plant at Ada, Pontotoc County; the limestone used is obtained from an open-pit quarry about 6 miles away. Crushed stone is produced in the same quarry. Very large quarries and crushing plants for production of concrete aggregate, road stone, and railway ballast are located at Crusher, Murray County; in southwestern Coal County not far from Bromide; at Stringtown, Atoka County; and at Hartshorne, Pittsburg County. Asphaltic limestone occurs near Dougherty, Murray County. Limestone production of western Oklahoma is confined to one quarry at Richards Spur, Comanche County, where road stone and railway ballast are prepared in large quantities.

Oregon.—In Oregon limestones occur principally in three widely separated localities—the southwestern, the northwestern, and the northeastern corners. Those of the southwestern area, occurring in Jackson and Josephine Counties, are of Devonian, Cretaceous, and probably Carboniferous age. Some contain only 5 per cent or less impurities and therefore are suitable for lime burning and chemical uses. Most limestones in the northwestern counties are impure. Very pure rock in beds

[66] Decker, C. E., and Merritt, C. A., Physical Characteristics of the Arbuckle Limestone. Oklahoma Geol. Survey Circ. 15. 1928. 54 pp.

at least 100 feet thick occurs in Baker County in the northeastern corner of the State. Deposits are found also in Grant, Union, and Wallowa Counties in the same section.

Very little limestone is consumed for road work or concrete aggregate in Oregon, as demands for such uses are supplied chiefly by trap rock and gravel. In the northeastern area lime and cement are manufactured at Lime, in southeastern Baker County; and lime is manufactured also at Enterprise, Wallowa County. In southwestern Oregon limestone is quarried at Gold Hill, Jackson County, for lime and cement manufacture, and stone from the same deposit is supplied to paper mills. Josephine County reports production for agricultural use, for paper mills, and for asphalt filler. The limestone industry of the northwestern area is represented by a cement plant near Oswego in northwestern Clackamas County.

Pennsylvania. *Reasons for Leadership.*—The limestone industries of Pennsylvania are far in the lead of those in all other States. Their preeminence is due to the presence of an abundance of high-grade stone and availability of very extensive markets. Enormous iron and steel industries use many thousand tons of fluxing and refractory stone. The State is populous, and its numerous cities and towns require a network of connecting roads. The road building involved in its wide system of highways consumes great tonnages of both limestone and cement. Extensive building construction demands crushed stone, cement, and lime, and the last product is used widely also in numerous chemical plants. Coal-mine dusting, agriculture, and many manufacturing industries also require large supplies of limestone. Not only are its home markets extensive, but the State occupies a strategic position for supplying outside markets in many industrial centers.

Geology of Limestones and Extent of Industry.—Limestones are widespread in Pennsylvania, but high-grade rock of greatest commercial importance is confined to the central and southeastern counties and to an area north of Pittsburgh near the western border. The oldest limestone, which is of pre-Cambrian age, occurs in relatively small outcrops in the southeast, notably in Chester, Bucks, Berks, and Northampton Counties. Most of it is coarsely crystalline. It has been used to a limited extent for crushed stone. Cambro-Ordovician limestones occur very prominently in many parts of central and southeastern Pennsylvania. Their great thickness and easy solubility compared with associated formations have made them the most important valley-forming limestones of the State. A prominent valley in this rock passes across the State through Easton, Bethlehem, Allentown, Reading, Lebanon, Carlisle, and Chambersburg. Lancaster Valley and York Valley are of similar origin. The beds are folded, and outcropping belts run, in general, northeast and southwest. The rock is variable in both structure and composition, as

the lower beds are generally higher in magnesium than the upper strata. Rock of a high degree of purity is used in many places. An argillaceous phase constitutes the famous "cement rock" in the Lehigh Valley district. The Cambro-Ordovician formation furnishes much of the raw materials for cement, lime, and crushed stone in the State.

The Helderberg and Tonoloway (Devonian-Silurian) limestones occur in south-central Pennsylvania in great, longitudinal folds that have been worn down by erosion. They appear as narrow curving, contorted bands running, in general, northeast and southwest. Frequently the rocks are siliceous and argillaceous, but very pure stone has been found in some localities. Hundreds of quarries are, or have been, worked in these beds for the manufacture of agricultural limestone, crushed stone, furnace flux, and lime. Other Silurian and Devonian limestones occur but have minor economic importance.

Carboniferous limestones are very widespread throughout the north-central and western half of the State. Occurrences are most numerous in the southwestern section and with the exception of the Vanport formation become less abundant and in general of less economic value toward the north and northeast. The stone is used locally in southwestern counties for lime burning and road construction. The Vanport (Pennsylvanian) limestone, which corresponds with the Ferriferous formation described in the section devoted to Ohio, is the most important of the Carboniferous rocks. It is used extensively in Armstrong, Butler, and Lawrence Counties for furnace flux, crushed stone, and the manufacture of lime and cement.

Detailed information on Pennsylvania limestones is given by Miller.[67]

The total value at the plant of limestone, cement, and lime produced in Pennsylvania in 1929 exceeded $75,000,000. Crushed and broken limestone, aside from that used for cement and lime manufacture, sold during the same year was valued at about $13,937,000, a larger sum than was obtained for similar products in any other State. Pennsylvania far exceeds all other States as a cement producer; the sales value exceeded $55,000,000 in 1929 and $31,000,000 in 1937. Pennsylvania has a greater number of lime plants than any other State, but in value of output Ohio usually leads by a wide margin. Pennsylvania stands second, with a sales value at the plant of nearly $5,900,000 in 1929 and $5,117,733 in 1937. The total value of crushed and broken limestone and its primary products, cement and lime, reached about $50,000,000 in 1937.

Cement Industry.—Twenty-seven or twenty-eight cement plants normally are in operation in Pennsylvania. Geographically they fall into two groups. The southeastern, which is by far the more important area comprises Northampton, Lehigh, Bèrks, Montgomery, and York

[67] Miller, B. L., Limestones of Pennsylvania. Topog. and Geol. Survey of Pennsylvania Bull. M 7, 1925, 368 pp.

Counties, while the western or smaller area includes Allegheny, Butler, and Lawrence Counties. Conditions strongly favor maintenance of a great industry in southeastern Pennsylvania. First, the abundant supply of raw materials consists chiefly of so-called cement rock, an argillaceous limestone in which the silica, alumina, and lime occur in approximately the proper proportions for a cement mixture, though in many places the composition must be adjusted by addition of a small percentage of limestone or shale. The rock is easily quarried and pulverized, and the intimate natural mixture of limestone and clay is advantageous. Second the district is located centrally with respect to large markets and is well-served with railroads. The easy availability of fuel supplies is a third favorable factor. This combination of advantages has resulted in development of a more extensive cement industry in Lehigh and Northampton Counties than is to be found in any other area of equal size in the world.

In Northampton County there are 4 plants near Nazareth, 3 near Bath, 2 at Northampton, and 1 each at Martin's Creek, Stockertown, Siegfried, and Sandt's Eddy. The cement mills of Lehigh County are at Coplay, West Coplay, Egypt, Fogelsville, Ormrod, and Cementon. Mills are operated also at Evansville, Berks County; West Conshohocken, Montgomery County; and York, York County. The dry process of manufacture is most generally used. All plants in the district obtain their rock from open-pit quarries.

In Lawrence County, in the western district, limestone from open-pit quarries is supplied to cement mills at Walford Station and New Castle, while stone for a mill at Wampum is obtained from an underground mine. In Butler County the Vanport limestone is mined underground for a cement mill at West Winfield. Two cement plants operate near Pittsburgh, Allegheny County, one at Neville Island and one at Universal. Both employ furnace slag to which Vanport limestone is added.

Lime Industry.—Pennsylvania has more lime plants than any other State; about 130 were active in 1929. As many of them which supply agricultural limestone for local use have a relatively small output, the aggregate production is much less than that reported from the 28 lime plants of Ohio. However, many large, well-equipped plants are operated. In the following brief reference to individual locations, many small plants that are chiefly of local interest are necessarily omitted. The most active production centers are in southeastern and central Pennsylvania.

In the southeastern section lime is produced in Adams County not far from Hanover. One of the largest high-magnesia lime plants of the State is at Devault, Chester County, and lime is produced also near West Chester in this county. Lime is manufactured at Swatara Station and Paxtang, Dauphin County and at Billmeyer and other localities in

Lancaster County. A high-grade bed of limestone in the Lebanon Valley, Lebanon County, supplies stone for lime plants at Annville, Myerstown, and Lebanon. Several important lime plants are located near York and Thomasville, York County, and near Bridgeport and Plymouth Meeting, Montgomery County. A small output is reported from Cumberland, Franklin, Northampton, and Perry Counties.

Centre County in central Pennsylvania is the most productive county in the State having several large well-equipped plants near Bellefonte and Pleasant Gap. Most of the raw material is obtained from a bed of very pure high-calcium stone approximately 80 feet thick dipping at a steep angle. A very large underground mine supplies stone to one plant near Bellefonte. Other lime plants in the central area are located at Naginey, Mifflin County; and at Jersey Shore, Muncy, and Williamsport, in southern Lycoming County. Smaller plants operate in Blair, Huntingdon, Juniata, Snyder, and Union Counties. In east-central Pennsylvania lime is burned at Bloomsburg and other points in Columbia County, at Danville and several other places in Montour County, and in Northumberland County.

Bedford County, in southwestern Pennsylvania, is an active producer, with plants at Everett, New Enterprise, and seven or eight other localities. Quite a number of small plants operate in Somerset and Westmoreland Counties.

No large lime plants are situated in western Pennsylvania. Lime is burned at Branchton, Butler County; at Reynoldsville, Jefferson County; and at Rose Point, Lawrence County. Smaller plants operate at other points in the above and in Armstrong and Indiana Counties.

Crushed-stone Industry.—As over 200 quarries produce crushed limestone in Pennsylvania, reference necessarily is confined to the chief production centers. The most active producing districts are in southeastern and central Pennsylvania, though there are several very large mines and quarries in the western part of the State. Unless otherwise noted, the quarried stone is used for concrete aggregate or as road material.

Southeastern District.—Quarries are operated at Springtown and other points in Bucks County. Montgomery County is an important source of dolomite. The principal quarries are at Bridgeport, Conshohocken, Plymouth Meeting, Norristown, and Ambler. Although large quantities are used for ordinary crushed-stone purposes, substantial quantities are employed as a refractory in steel furnaces and as a raw material for magnesia for "85 per cent magnesia" pipe covering. Stone from one quarry at Bridgeport is pulverized and sold as filler in rubber, asphalt, and other products. Very extensive dolomite quarries are worked at Devault, Berwyn, Malvern, West Chester, and Howellville, Chester County, part of the product being used as a source of magnesia for pipe

covering, for filler, and as agricultural limestone. West of Hanover, Adams County, high-calcium limestone is quarried very extensively for furnace flux, as well as for road stone and concrete aggregate.

York County is a very important producer of limestone. One large quarry near York supplies great quantities of fluxing stone and several produce road stone, concrete aggregate, stone for refractory uses, and pulverized stone for filler. A large quarry at Thomasville produces stone for furnace flux, glass and paper mills, and agricultural purposes. Scores of quarries operate in the high-grade limestone beds of Lancaster County. The largest of these, at Bainbridge, produces stone for iron furnaces and paper mills, as well as for ordinary crushed-stone products. Other important quarries are at Rheems, Lancaster, Columbia, East Petersburg, Blue Ball, Quarryville, West Manheim, Mount Joy, Bareville, and Ephrata. Several large quarries are worked in Berks County, notably at Shillington, South Temple, Reading, West Leesport, and Wernersville. Large quarries at and near Allentown supply that populous center in Lehigh County, and limestone is quarried also at other points. Northampton, Nazareth, Easton and Bethlehem are the chief quarry centers of Northampton County; the Bethlehem quarries supply large quantities of fluxing stone for the iron and steel industry of that city.

A belt of high-calcium limestone passing through Lebanon County is worked in several places, though quarrying is difficult owing to an excessive flow of water. Much stone from this area is used by cement plants in Lehigh and Northampton Counties to raise the calcium carbonate content of the cement rock. Fluxing stone and agricultural limestone are other important products. The chief quarry centers are Annville, Lebanon, Donaghmore, Myerstown, and Palmyra.

The largest quarry in Dauphin County is at Steelton. The principal product is fluxing stone for use in furnaces located near the quarry. A large modern crushing plant was recently built. Fluxing stone is obtained also at Swatara Station. A new crushing plant of modern design serves a large quarry near Harrisburg. Paxtang, High Spire, Hummelstown, and Hershey are other limestone-quarry centers in this county. Crushed stone is produced near Bloomsburg, Columbia County; and at Mausdale, Montour County.

Cumberland County is an active producer, with quarries at Carlisle, Camp Hill, Lemoyne, Shippensburg, and Newville. In Franklin County large quarries operate at Williamson, Waynesboro, and Chambersburg and quite a number of smaller ones at various points. Limestone for road construction is quarried at Landisburg and Blain, Perry County.

Central District.—Ganister, Blair County, is an important center of production of fluxing limestone. Crushed limestone is produced also

at Canoe Creek, Frankstown, Duncansville, Roaring Spring, and Tyrone in this county.

An important limestone in Centre County is suitable for a variety of uses, and large quantities are quarried for furnace flux, coal-mine dusting, glass factories, and agriculture in addition to that devoted to the more common uses, such as concrete aggregate and road building. The principal quarries are near Bellefonte, Oak Hall Station, State College, and Pleasant Gap.

A quarry at Salona, Clinton County, produces concrete aggregate, road stone, and railroad ballast. Large quarries are worked at Union Furnace, Mapleton Depot, and Orbisonia, Huntingdon County; and at Naginey, Mifflin County. One of the Naginey quarries has been developed recently and is well-equipped to produce great quantities of fluxing stone for use in open-hearth steel furnaces. Crushed stone is produced at Jersey Shore, Muncy, and Chippewa, Lycoming County, and at various points in Snyder and Union Counties.

Southwestern and Western Districts.—Ashcom, Hyndman, and Waterside are the principal quarry centers of Bedford County. A great many small quarries, most of them now inactive, are to be found in many parts of Westmoreland County. Road stone is quarried at several places in Somerset County, chiefly at Garrett.

High-grade deposits of Vanport limestone in several western counties have great economic value because of their proximity to the extensive iron and steel industries of the Pittsburgh district. Most of them, however, have the disadvantage of a very heavy overburden; in consequence, large underground mines have been developed. What is probably the largest limestone mine in the country, capable of producing 3,500 tons of stone a day, is operated at Kaylor, Armstrong County. Other mines in this county for production of fluxing stone are located at Worthington, Kittanning, and Templeton. In Butler County very extensive mines whose chief product is fluxing stone are located at Annandale, Osborne, Branchton, and West Winfield.

Enormous quantities of limestone are produced in Lawrence County. One underground mine is worked near Ellwood City, but the great bulk of production is from a series of large open pits near Hillsville. During a normal year between 2 and 3 million tons of fluxing stone, with substantial supplies of crushed stone for concrete aggregate, road building, and agricultural limestone, are produced in this district. A large open quarry is worked at Rose Point. Road stone is produced near Clarion, Clarion County.

Rhode Island.—Commercial limestone occurrences in Rhode Island are confined to the vicinity of Lime Rock, Providence County, in the northern part of the State. The stone is used principally for lime manufacture in one lime plant, with a minor production of stone for furnace

flux and other uses. The lime may be classed as low-magnesian, a typical analysis of the stone showing about 9 per cent magnesium carbonate. Limestone beds occurring in other parts of the State are too small to have economic importance.

South Carolina.—Metamorphosed limestone or marble occurs in western South Carolina and soft Tertiary limestones or marls on the Coastal Plain. Most of them are high in silica but might prove satisfactory for cement manufacture. No cement has yet been made in the State. Crushed limestone is produced at Gaffney, Cherokee County, and agricultural limestone at Saint Matthews, Calhoun County.

South Dakota.—Limestones occur in the Black Hills district of western South Dakota and in the eastern part of the State. The Black Hills uplift of crystalline rocks brought with it a series of Paleozoic and Mesozoic sediments which dip outward toward the plains. Limestones of various ages appear where the upturned strata have been partly eroded away. The more important are the Englewood and Pahasapa, of Mississippian (Lower Carboniferous) age, and the Minnekahta, of Pennsylvanian (Upper Carboniferous) age. The latter contains considerable magnesium. The Niobrara (Cretaceous) chalk underlying most of South Dakota averages about 150 feet in thickness. It appears most prominently in the southeastern part of the State, where it outcrops in many places along the Missouri River from Yankton to Fort Thompson and in the James River Valley.

Limestone quarries are confined almost exclusively to the Black Hills district. The State has one cement plant, at Rapid City, Pennington County. Recent production of lime has been confined to plants in Pennington County near Rapid City, but lime is produced at times in Custer, Lawrence, and Meade Counties. The largest quarries for production of crushed stone are near Rapid City, Pennington County. The products are concrete aggregate, road stone, and limestone for sugar mills. Smaller quarries are operated in Custer, Lawrence, and Fall River Counties. Except for small local quarries in southeastern counties the Niobrara chalk has no commercial use at present.

Tennessee.—Limestones abound in Tennessee, particularly in the eastern and central regions. The most important of the oldest (Cambrian) limestones is the Knox dolomite, although the upper part of the Knox is classed as Ordovician. East of the valley of the Tennessee River, which passes through Knoxville, Ordovician limestones are plentiful. The lowest bed is the Chickamauga, part of which is argillaceous; but the part known as the Holston formation is a very pure, high-grade, crystalline rock that has made Knoxville famous as a marble center. Other limestones occur at higher levels, but most of them are impure. On the western side of this valley Chickamauga limestones, 1,200 to

2,000 feet thick, occur in great abundance. Some parts of the formation are pure, while other beds are argillaceous.

The lowest available limestones of middle Tennessee are those of the Stones River group, of Ordovician age. The Murfreesboro is the lowest member, and following in order are the Pierce, Ridley, Lebanon, and Carters. They consist of pure to argillaceous limestones, most of which are low in magnesium. The Carters, which occurs in most of the counties of the central basin, is widely used for lime burning. Limestones, of Trenton age, many of which are argillaceous, form an irregular belt which entirely encircles those of the Stones River group. Above the Trenton are the Cincinnatian (Upper Ordovician) and the Silurian and Devonian limestones; the latter occur prominently in middle, west-middle, and northern Tennessee. Like the Trenton rocks, many of them contain considerable clay and shale. The Mississippian (Carboniferous) formation, which occurrs most prominently in the northern and western counties of middle Tennessee, contains high-grade limestone in places.

The total value at the plant of limestone and its principal primary products (cement and lime) produced in Tennessee in 1929 approached $9,000,000, and in 1937, approximately $7,900,000. Cement plants, lime kilns, and quarries for production of raw limestone are widely scattered throughout the eastern and central areas. Recent additions of cement plants, raising the total of the State to six, has made Tennessee an important producer, with normal annual value of cement reaching 5½ to 6½ million dollars.

In eastern Tennessee two cement plants are in operation. One of the long-established mills at Kingsport, Sullivan County, is supplied with limestone from a quarry at Speer's Ferry, Va. A plant at Caswells Station east of Knoxville, Knox County, uses the Holston marble as its calcareous raw material. Mississippian beds furnish limestone to one of the newer cement plants at the base of Signal Mountain near Chattanooga, Hamilton County. A short distance west, at Richard City, Marion County, is the oldest plant of the State; it was first operated in 1907. Other plants are located at Cowan, Franklin County, and at Nashville, Davidson County; the latter plant uses Ordovician limestone.

Knox County produces the most lime; the pure high-calcium Holston marble supplies raw material for several plants near Knoxville. All the other important lime plants are in central Tennessee. Lime is manufactured at Crab Orchard, Cumberland County; and at Summitville, Coffee County. The largest plant in the State (at Sherwood, Franklin County) is equipped with both rotary and shaft kilns. Other lime-producing centers are Watauga, Carter County; Burns, Dickson County; Erin, Houston County; Palmyra, Montgomery County; and Columbia, Maury County.

The crushed-limestone industry extends throughout the same general territory as the lime and cement industries, namely, the eastern and central counties. Stone is quarried for concrete aggregate and road building at Bristol, Kingsport, and other points in Sullivan County near the eastern tip of the State; road stone at Johnson City, Washington County; and furnace flux near Milligan College and Watauga, Carter County. The largest quarries are in Knox County near Mascot and Strawberry Plains. Many thousand tons of railroad ballast, concrete aggregate, and road stone are produced, as well as large supplies of roofing gravel, asphalt filler, and agricultural limestone. Stone for railroad ballast and other uses is quarried at Crab Orchard, Cumberland County. Another large quarry is located at Harriman, Roane County, and smaller ones in Blount, Loudon, and Campbell Counties. Quarries are worked in Coffee, Rutherford, Marshall, and White Counties in central Tennessee. Limestone quarried at Sparta in the latter county is pulverized and sold as filler. Crushed limestone is produced at Sherwood, Franklin County, and at East Chattanooga and other points in Hamilton County. Antioch and Nashville, Davidson County, and Franklin, Williamson County, are important quarry regions in western-central Tennessee. Impure limestone quarried at Rockdale, Maury County, is used for the manufacture of mineral wool. Crushed stone is obtained at Clarksville, Montgomery County, and in Wilson County, while fluxing stone is quarried in Hickman County.

Texas.—Limestones are distributed widely in Texas, particularly in the eastern half of the State. The Ellenburger limestone, of Cambro-Ordovician age, occurring in east-central Texas, is a hard, light-colored rock recrystallized to marble in places. Carboniferous and older Palaeozoic rocks occurring in the north-central region are used to a limited extent.

The most important limestones for cement, lime, and crushed-stone uses are of Cretaceous age. The Austin Chalk, which is of especial importance as a cement-making material, occurs in a well-defined belt in east-central Texas. From Red River in the northeastern part of the State it extends westward near Clarksville, Honeygrove, Paris, and Sherman. From Sherman it extends south and southwest beneath Dallas, Waco, Austin, and San Antonio, terminating a little southwest of the last city. It is 400 to at least 600 feet thick and in many places remarkably uniform. Analyses show a calcium carbonate content of 70 to more than 90 per cent and very little magnesium. It occurs in the most populous part of Texas, and quarry conditions are favorable.

The Fredericksburg group of Lower Cretaceous Age outcrops west of the Austin Chalk. There are three important members—the Goodland at the north, and the Edwards and the Comanche Peak to the south. The limestones of this group occur in large areas in Wise, Parker, Hood,

Erath, Bosque, Hamilton, Coryell, Lampasas, Burnet, Blanco, Kendall, Comal, and Bexar Counties. Still larger areas are exposed in the Edwards Plateau west of San Antonio. Ordovician, Silurian, Carboniferous, and Cretaceous limestones occur in western Texas near El Paso. The Ordovician is used for lime and the Lower Cretaceous for the manufacture of cement and fluxing stone.

With 9 or 10 plants normally in operation and a production value of nearly $12,000,000 in 1929 and $11,490,000 in 1937, Texas is an important producer of cement. In the former year the lime output was valued at more than $838,000, and limestone sold in the raw state in crushed and broken form at about $2,300,000. Corresponding figures for 1937 were $440,000 and about $1,397,000.

Most Texas cement plants are on the Cretaceous belt. Two near Dallas, Dallas County, one at Waco, McLennan County, and two near San Antonio, Bexar County, use the Austin Chalk, and a plant at Fort Worth, Tarrant County, Lower Cretaceous limestone. Three cement plants operate near Houston, Harris County; one utilizes oyster shells as calcareous raw material. A plant at El Paso, El Paso County, western Texas, is supplied with limestone from Lower Cretaceous beds.

The lime industry of western Texas is confined to a group of plants near El Paso, El Paso County. A plant first operated in 1929 near Houston, Harris County, employs a gas-fired rotary kiln to calcine oyster shells into lime. The other lime plants of the State are in the east-central district. The largest are at New Braunfels, Comal County; McNeil, Travis County; and Round Rock, Williamson County. Lime is also produced at Lime City near Oglesby, Coryell County; and, according to report, a new plant was built at Big Spring, Howard County, in 1931.

Except for large quarries at El Paso producing concrete aggregate, road stone, and smaller quantities of furnace flux, practically all of the crushed-limestone plants are in the east-central area. In the north-central district large quarries are worked at Jacksboro, Jack County; Bridgeport and Chico, Wise County; Salesville, Palo Pinto County; and in Shakelford and Jones Counties. The products are road stone and concrete aggregate, with a smaller output of railroad ballast. Farther south large operations are conducted at Tiffin, Eastland County, chiefly for railroad ballast, with smaller quantities of concrete aggregate, road stone, and riprap. Ballast is produced in Brown County, and large quantities of both ballast and road stone are quarried at Richland, Navarro County. The largest establishment in southern Texas is at New Braunfels, Comal County, where many thousands of tons of concrete aggregate, road stone, and railroad ballast are produced. San Antonio, Bexar County, is another important center, where several quarries produce crushed stone, road base, ballast, and stone for filter

beds. Road material is quarried in Milam County and also in Sutton County farther west.

A coarse-grained, asphalt-bearing limestone of Upper Cretaceous Age, associated with igneous intrusions, is quarried extensively near Uvalde, Uvalde County, and in Kinney County. Average rock consists of 10 to 12 per cent asphalt and 88 to 90 per cent limestone, a proportion which gives very satisfactory road-building material. The stone, shattered with dynamite, is loaded by steam shovels into standard-gage railroad cars and hauled to a central crushing plant, where it is crushed, pulverized, screened, and blended with asphaltic flux oil. It is claimed that 1 ton of stone will cover 20 square yards of pavement 1 inch thick. It is produced on a large scale and has been used in surfacing hundreds of miles of highways, chiefly in Bexar County.

Utah.—The most important limestones of Utah are those of Carboniferous age, which occur in many parts of the Wasatch Mountains in the northern and north-central counties. Many of the deposits are argillaceous, a condition which is not detrimental for cement manufacture but is undesirable for most other uses. However, quite a number of occurrences are pure enough for the manufacture of lime and for use in sugar mills. Softer limestones, of Eocene age, occur in the Plateau district. Marl deposits in an ancient bed of Great Salt Lake are also available.

Although Utah has some important cement and lime industries, limestones have not been utilized extensively in other ways. Quarries are confined almost exclusively to the northern and north-central regions.

The oldest cement plant of the State is at Salt Lake City, Salt Lake County. Its calcareous raw material is obtained from limestone beds, probably of Carboniferous age, at Parley's Canyon several miles southeast of the city. Another large plant at Devils Slide, Morgan County, also employs Carboniferous limestone. A cement plant built at a later date at Bakers, Box Elder County, is supplied with marl and underlying clay from an abandoned bed of Great Salt Lake.

The largest output of lime in the State is in Salt Lake County, where one large and several smaller plants produce it for building and for metallurgical use in the important smelters and ore-treatment plants of Salt Lake City. A plant at Garfield is unique in that it utilizes limestone sand as raw material. Lime is made also at Logan, Cache County; near Ogden, Weber County; at Grantsville, Tooele County; and in the southwest corner of Utah County near Eureka. A small plant near Salina, Sevier County, produces lime for building and for sugar manufacture. A small output is reported from Cedar City, Iron County, near the southwestern corner of the State.

The crushed-limestone industry of Utah is relatively small and is peculiar in that very little of the product is used for the more common

applications, namely, as road stone or concrete aggregate. At Lucin and Lakeside, Box Elder County, considerable quantities of railroad ballast are produced as occasion demands. The chief production is at Topliff, Grantsville, and other points in Tooele County, to provide stone for furnace flux and, in smaller quantities, for sugar mills. Fluxing stone is produced also in Salt Lake County, and pulverized stone for coal-mine dusting at Devils Slide, Morgan County. Limestone is furnished to sugar factories from quarries in Cache, Sevier, Salt Lake, and Utah Counties, and for use as poultry grit in the last two counties.

Vermont.—The calcareous rocks of Vermont are of two distinct types. Marbles occurring abundantly in the Champlain Valley, passing through Brandon, Rutland, and Dorset, have been described in some detail in the chapter devoted to the marble industry. The second type comprises the noncrystalline limestones of Ordovician age (Chazy and Trenton), occurring principally in the northwestern counties, Addison, Chittenden, and Franklin. Most of the marbles are very pure and low in magnesium. The limestones are more variable in composition, but most of them contain only a small amount of magnesium.

Suitable stone for cement manufacture is obtainable in Vermont, but an industry has not been established because the State is handicapped by limited local markets and high-priced fuel.

The largest lime plant, at West Rutland, Rutland County, uses waste marble, which is very abundant in this region. It is calcined in a rotary kiln. Moderate-sized lime plants operate at Fonda Junction, St. Albans, and Swanton, Franklin County; Winooski, Chittenden County; Leicester Junction and New Haven Junction, Addison County; and Amsden, Windsor County.

Crushed-limestone production is small, and much of it consists of by-products at lime plants. Road stone and concrete aggregate are produced in limited quantities at Swanton, Franklin County, and near Burlington, Chittenden County. Agricultural limestone is, or has been, ground at Winooski in the latter county and in Bennington County. Terrazzo chips are manufactured from waste marble at West Rutland and Brandon, Rutland County, and at Middlebury, Addison County. Road stone and agricultural limestone are also produced in the latter county and a small quantity of agricultural limestone in Windham and Windsor Counties.

Virginia.—The famous Shenandoah Valley and similar valleys lying northwest of the Blue Ridge Mountains contain the valuable Virginia limestones. The most important members are the Shady dolomite, of Cambrian age, and the Lenoir, Mosheim, and Holston limestones, of Ordovician age. The Mosheim is the highest grade limestone of the state and is practically continuous from Maryland to Tennessee and beyond. Limestones of these formations have great commercial value in

the two western tiers of counties throughout the entire length of the State, except Buchanan and Dickenson Counties, which are west of the valley region.

Helderberg (Devonian) limestone occurs in the Alleghany Mountains. It is quite variable in composition but has been found satisfactory for cement manufacture in Augusta County. Greenbrier and Newman limestones, of Mississippian age, occur in narrow bands in the southwestern corner of the State, beds of maximum thickness appearing near Cumberland Gap at the Tennessee border.

Tertiary shell beds or shell marls occur in the eastern Coastal Plain district, chiefly in Norfolk, Nansemond, Isle of Wight, Surry, York, and Gloucester Counties. They consist of shells of various molluscs mixed with sand and clay. They have little practical value, except for manufacture of cement.

The limestone industries of Virginia have considerable importance. The value of the output of cement is unrecorded because of the small number of plants. Lime sold in 1929 was valued at over $1,000,000 and the production of crushed limestone at nearly $2,500,000. Corresponding figures for 1937 were $1,248,479 and $3,016,899.

Virginia has two cement plants. One, which uses Tertiary shell deposits as raw material, is favorably situated at South Norfolk, Norfolk County. The second plant, using the Helderberg limestone, is at Fordwick, Augusta County.

Over 30 lime plants are normally in operation, nearly all of them in the Appalachian Valley in the western part of the State. One of the few producing districts in the Piedmont east of the Blue Ridge is at Leesburg, Loudoun County. The largest plants in the State are at Stephens City, Frederick County; and at Riverton, Warren County. Other important lime plants in the northwestern area are at Limeton, Warren County; and at Oranda, Strasburg, Strasburg Junction, and Toms Brook, Shenandoah County. In the west-central area lime plants operate at Linville and Bridgewater, Rockingham County; several small plants are located at Staunton and other points in Augusta County; and three large plants, one at Indian Rock and two at Eagle Rock, are located in Botetourt County. In the southwestern part of the State lime plants are located at Kerns and Ripplemead, Giles County; and at Maxwell, Richlands, and Tazewell, Tazewell County. A small output is reported at times from Montgomery County.

Crushed limestone is produced in large quantities in Virginia and is applied to a great variety of uses. In the northwestern area road stone and concrete aggregate are produced at Leesburg, Loudoun County; and the same products, with fluxing stone and agricultural limestone, are prepared at Stephens City and Winchester, Frederick County. Railway ballast and other forms of crushed stone are produced at Riverton and

Limeton, Warren County, as by-products of lime industries. Large quantities of road stone have recently been quarried at Strasburg, Toms Brook, Mount Jackson, and New Market, Shenandoah County, mainly for improvement of the famous Shenandoah Valley pike.

In the west-central area quarries for the production of road stone and aggregate are maintained at Harrisonburg and other parts of Rockingham County; at Waynesboro, Staunton, New Hope, and other points, in Augusta County; and at Hot Springs, Bath County. Crushed stone for railroad ballast and other uses is produced in Rockbridge County. Agricultural limestone and fertilizer filler are the chief products of quarries near Falling Springs, Alleghany County. Many thousand tons of road stone and railroad ballast are produced at Blue Ridge and Rocky Point, Botetourt County, and quarries at the latter place produce stone also for furnace flux, paper mills, agricultural use, asphalt filler, and for coal-mine dusting. Road stone is quarried near Bonsacks, and both flux and road stone are sold as by-products of lime industries situated near Buchanan and at Eagle Rock.

In southwestern Virginia large quarries are worked for road stone and ballast production near Roanoke, Roanoke County; near East Radford, Pulaski County; and at Pembroke and Ripplemead, Giles County. Stone for carbide manufacture is produced near Kerns, Giles County. A large quarry at Ivanhoe, Wythe County, at times provides limestone for calcium carbide manufacture, and agricultural limestone is produced at Austinville. Fluxing stone is obtained at Pulaski. Agricultural limestone and road stone are other important products of Pulasli County. One of the largest quarries in the State supplies stone for alkali manufacture at Saltville, Smyth County, while quarries at Marion and other points produce ballast and road stone. Other important limestone-quarry centers in the southwest are at Pounding Mill, Tazewell County; and Wheeler, Lee County. Quarries are also operated in Russell, Washington, Wise, and Scott Counties. A quarry at Speer's Ferry, Scott County, supplies limestone to a large cement plant at Kingsport, Tenn.

Washington.—Northwestern Washington has the distinction of possessing the only extensive limestone deposits on deep water along the Pacific coast of the United States. The more important of the coast deposits are the highly crystalline limestones, of Devonian, Carboniferous, and Triassic ages, on San Juan and Orcas Islands. On San Juan Island they outcrop in heavy beds, reaching a height of 200 feet above tidewater. Similar crystalline limestones occur near Kendall, Whatcom County; near Granite Falls, Snohomish County; and in eastern King County. They also outcrop in various parts of northern and northeastern counties near the British Columbia boundary. The northeastern limestones range in age from possible pre-Cambrian to Carboniferous.

As six plants normally are in operation in Washington the manufacture of cement is an important industry, but the lime and limestone industries are relatively small. Crushed-limestone products sold in 1929 were valued at about $130,000 and the lime output at about $325,000. Figures for cement are not available.

Four of the six cement plants are in western counties, and two are close to the eastern border of the State. A plant at Bellingham, Whatcom County, uses crystalline limestone quarried at Balfour 35 miles away. Marketing of the product is favored by availability of water transportation. A mill at Concrete, Skagit County, is supplied with limestone quarried about 2 miles away and brought to the plant by aerial tramway. A cement mill at Seattle, King County, is unusual in that its limestone supplies are shipped by water from Dall Island, Alaska, about 700 miles. A plant at Grotto, in northeastern King County, uses local limestone. A cement mill that has operated for many years at Metaline Falls, Pend Oreille County, near the northeastern corner of the State uses crystalline limestone occuring near the plant. Limestone supplies for a cement mill at Spokane, Spokane County, are shipped by rail from a quarry at Lakeview, Idaho.

The lime industry of Washington is confined to the northwestern and northeastern corners of the State. There are several plants at Roche Harbor, Friday Harbor, and other points on Orcas and San Juan Islands, San Juan County. The crystalline limestones of these islands calcine to a very pure lime, and availability of water transportation is an added asset. Lime is manufactured near Bossburg, Stevens County, from high-calcium marble. Dolomite calcined at Colville in this county is used in paper manufacture.

Relatively small amounts of crushed limestone are produced in Washington and very little of it is used, except locally, for road stone or concrete aggregate. The crystalline limestones of San Juan County are quarried to supply paper mills, glass factories, and sugar refineries and for manufacture of furnace flux and poultry grit. The limestones or marbles quarried in northern Stevens County are sold chiefly to paper mills or as furnace flux, with smaller amounts for agriculture, poultry grit, terrazzo, and coal-mine dusting.

West Virginia.—The more important limestones of West Virginia occur in Jefferson and Berkeley Counties by virtue of the fact that they intersect the Shenandoah Valley, which is traversed by a broad belt of rock known formerly as the Shenandoah limestone; its important members are the Shady dolomite, of Cambrian age, and the Mosheim limestone of Ordovician age. One member of the Shenandoah group—the Stones River of Ordovician age—furnishes high-quality limestone which is particularly well-developed in the northeastern counties of West Virginia. The rock is admirably suited for furnace flux, chemical

uses, and cement manufacture. Other members of the Shenandoah formation provide high-grade dolomites that are utilized extensively for basic refractories. A detailed description of the limestones in this area has been published.[68]

Other limestones, of Cambrian, Ordovician, Silurian, Devonian, and Mississippian ages, outcrop in the folded territory of other eastern and southeastern counties, but few approach in purity those of the northeastern Panhandle region. Some are of high quality, for use in crushed form as concrete aggregate, road stone, or railroad ballast, and are quarried for such purposes, particularly in Greenbrier, Pocahontas, Preston, and Monongalia Counties. They also provide raw material for cement manufacture in Preston County.

The limestone industries of West Virginia are of considerable magnitude. Three cement plants are in operation, but figures for value of production are not available. Normally about a dozen lime plants are active, their output being valued at more than $1,800,000 in 1929 and $1,617,040 in 1937. Crushed and broken limestone produced was valued at nearly $3,000,000 in 1929 and more than $2,450,000 in 1937.

A cement plant at Martinsburg, Berkeley County, employs Shenandoah limestone as its calcareous raw material. A second plant, at Manheim, Preston County, is provided with limestone from large, carefully planned underground workings. The third cement mill of the State, at Kenova, Wayne County, is supplied with limestone quarried at Lawton, Ky.

All the larger lime plants of West Virginia are in the northeastern Panhandle district, where high-grade Stones River limestone is available. Chief centers of production are near Martinsburg and Berkeley, Berkeley County; and at Bakerton and Millville, Jefferson County. A high-grade dolomite occurring near Millville in the latter county is quarried extensively for manufacture of refractory dead-burned dolomite. Lime is manufactured at Terra Alta, Preston County, and small kilns are located at several other places in that county. Lime and dead-burned dolomite are manufactured at Kenova, Wayne County, from dolomite shipped to the kilns from quarries at Peebles, Ohio.

Aside from that used in the manufacture of cement and lime, nearly two thirds of the crushed and broken limestone of West Virginia is sold as furnace flux. The most important production centers are Falling Waters and Martinsburg, Berkeley County; and Millville and Engle, Jefferson County. Most of the furnace flux is used in the Pittsburgh (Pa.) district. Crushed stone produced at most of the above locations and also at Berkeley is sold as railroad ballast, concrete aggregate, and road stone; for glass manufacture; and in pulverized form, as agricultural

[68] Grimsley, G. P., Jefferson, Berkeley, and Morgan Counties. West Virginia Geol. Survey, 1916, pp. 361–583.

limestone and asphalt filler. Large quantities of ballast, concrete aggregate, and road stone are produced at Fort Spring, Renick, and near Frazier, Greenbrier County. Other quarries for production of crushed stone or agricultural limestone are operated at Greer, Monongalia County; and at Wheeling and other points in Ohio County. Many small quarries have been worked in Preston County, but most of them are now inactive.

Wisconsin.—Pre-Cambrian rocks, which are enveloped by succeeding belts of Paleozoic sediments, occupy the north-central and northern sections of Wisconsin. Limestones appear in a broad belt along the eastern side of the State, extend across the southern part, and are available in certain areas along the western side. They dip in a general way toward the nearest boundary of the State. The principal formations are the Lower Magnesian, Platteville (Trenton), and Galena, of Ordovician age, and the Niagara, of Silurian age. A small occurrence of limestone, younger than the Niagara, appears north of Milwaukee. Like those of Minnesota, the limestones of Wisconsin are of the high-magnesian type, and nearly all of them are dolomites. They are unsuited for cement manufacture but are well adapted for making high-magnesian and special limes, and for many uses in crushed, broken, or pulverized form.

The output of cement in the State is small, but other limestone products are manufactured in large quantities. Eighteen or twenty lime plants are operated in times of normal business activity. Their production was valued at more than $1,000,000 in 1929 and at $508,536 in 1937. In the number of active limestone quarries within its borders Wisconsin is exceeded only by Pennsylvania and Ohio. The value at the quarry of crushed and broken limestone sold in 1929 exceeded $3,800,000, and in 1937, $2,338,000.

The only cement plant in the State is operated at Manitowoc, Manitowoc County. As all the limestones in this territory are dolomitic, supplies of calcareous raw materials are obtained from a Michigan Lake port. A cement-packing plant is maintained at Milwaukee.

The lime industry is confined to the east-central counties. Plants are operated near Green Bay, Brown County, from limestone shipped from Michigan. It is also manufactured at Brillion, Hayton, and Highcliff, Calumet County. Manitowoc County is an important center of production. Special grades of high-magnesian lime produced at Francis Creek near Manitowoc are sold for polishing and buffing. Plants are operated also at Grimms, Quarry, and Valders. Sheboygan, Sheboygan County; Eden, Fond du Lac County; Nasbro, Mayville, and Knowles, Dodge County; and Cedarburg, Ozaukee County; are other important centers of high-magnesian lime production.

Crushed limestone is produced principally in the eastern and southeastern sections. The most northerly, as well as the largest quarry in the State, is at Sturgeon Bay, Door County. Quarries are operated also at Green Bay, Duck Creek and other points in Brown County; at Kaukauna, Outagamie County; at Oshkosh and Menasha, Winnebago County; at Highcliff, Hayton and Brillion, Calumet County; and at Grimms, Quarry, Valders and Manitowoc, Manitowoc County. Limestone is quarried at Eden, Oak Center, Ripon, and Hamilton, Fond du Lac County; and in conjunction with lime manufacture at Sheboygan, Sheboygan County. Quarries are in operation at Nasbro and Mayville, Dodge County, and at Cedarburg and other points in Ozaukee County. The chief production in Waukesha County is centered near Waukesha. The main product is crushed stone for road work and concrete aggregate; smaller amounts are employed as flux, agricultural limestone, asphalt filler, and poultry grit. Other important quarries are at Lannon, where riprap and crushed stone are produced. Large quarries at Wauwatosa, and Milwaukee, Milwaukee County, supply that populous region, and even larger operations are conducted near Racine, Racine County, near the southeastern corner of the State. By far the largest proportion of all limestone quarried in the eastern area is for road construction and concrete aggregate, with smaller amounts for furnace flux, agricultural limestone, railroad ballast, stucco, and riprap.

Other important limestone centers, though comprising a less-productive area than the eastern, are scattered throughout western and southwestern counties, principally along the Mississippi River. Crushed stone is produced at Wilson, St. Croix County; in Buffalo County; and at Elmwood, Pierce County. Agricultural limestone is an important supplementary product of the latter region. Road stone and concrete aggregate are produced at La Crosse and other places in La Crosse County; in Sauk County; and at Hillsboro, La Farge, Springville, and other points in Vernon County. Riprap for shore protection along the Mississippi River is an important product of the last county. Many quarries for production of crushed stone are operated in Grant County in the southwest corner of the State, at Fennimore, Blue River, Cassville, Lancaster, Kieler, Bloomington, Mount Hope, Wyalusing, and other points. Lafayette and Green Counties at the southern border record an output of crushed limestone for large highway construction projects. Many small local quarries having an aggregate production of considerable magnitude produce highway-surfacing limestone in Richland, Iowa, and Crawford Counties.

Wyoming.—Limestones are found in many parts of Wyoming but have not been developed extensively. The best-known deposits are in Albany, Laramie, and Platte Counties in the southeast and in Weston

County in the northeast. Most of them are of the high-calcium type, and many deposits low in impurities are available.

No lime has been made in Wyoming during recent years, but the State has one cement plant. Aside from that used for cement, more than 80 per cent of the limestone quarried in Wyoming is used in beet-sugar manufacture. Limestone sold was valued at about $475,000 at the quarries in 1929 and at $317,000 in 1932.

A cement plant began operation at Laramie, Albany County, in 1929. Its limestone supply is obtained from Niobrara (Cretaceous) beds 9 miles west of the mill.

One of the largest quarries in the country to supply limestone for sugar factories is at Horse Creek, Laramie County. The same product is obtained at Granite Canon and other points in this county. Stone to supply sugar factories is obtained in substantial quantities at Guernsey and Hartville, Platte County, and this county is also a source of road stone and riprap in small amount.

QUARRY METHODS AND EQUIPMENT

Preliminary Steps.—Establishment of the quality and quantity of limestone available in a deposit is an important preliminary step. Methods of rock exploration and removal of overburden from the rock surface, have already been described in the chapter on prospecting and development.

Plan of Quarry.—Limestone is a sedimentary rock deposited in successive horizontal layers or strata. In some important quarry regions, particularly throughout the Middle West, the original beds are practically undisturbed, the strata remaining horizontal or inclined at low angles. The method of quarrying such deposits is usually simple. Beds are worked from open-pit quarries, except in a few localities where the overburden is so heavy that underground methods are used. The depth of quarrying depends greatly on the thickness of the strata of good stone. If beds are flat-lying and relatively thin, the pit must be enlarged laterally, and the extent of the area available and depth of overburden are matters of first importance. Thus, at Marblehead, Ohio, a 22-foot horizontal bed of rock with very light overburden has been removed from an area of more than 1 square mile. If beds are thick, deeper and narrower quarries may be developed, and this method will involve less extensive stripping.

In other regions, notably in the Appalachian Mountain district of eastern United States, the beds are folded so greatly that they may stand at steep angles, sometimes approaching the vertical. Quarrying such deposits is more complex. If beds are tilted at steep angles and are many feet thick, deep quarrying may be pursued. If tilted beds are

thin, any lateral extension must be in the direction of the strike or outcrop. If the beds dip at steep angles, the quarry may be worked to considerable depth, but removal of waste rock to avoid a dangerous overhang involves ever-increasing expense as the quarry is deepened. A narrow working face is a great disadvantage in quarrying steeply inclined beds of limited thickness; operations are cramped, and a large daily tonnage is difficult to obtain. This condition may be partly overcome by quarrying at several levels, so that each bench provides an additional working face. If work beyond moderate depths is necessary, resort to underground methods may be advisable.

Quarry Processes. *Drilling.*—Piston drills are used in many localities for drilling horizontal, inclined, or vertical holes for primary blasting. Where an irregular or seamy rock surface makes vertical drilling difficult, blasting sometimes is done in horizontal or inclined holes known as "snake holes" driven at the base of the bench. For this purpose piston drills usually are employed. Some years ago steam supplied the power to nearly all piston drills. Steam is not economical, as losses of heat by radiation and condensation are very high, although they may be overcome somewhat by insulating the pipes or using superheaters. Compressed air has proved much more economical and is now generally used.

Hand-manipulated compressed-air hammer drills are used to some extent in primary drilling, but chiefly in secondary drilling in preparing for pop shots to break up the larger fragments. Although hammer drills work rapidly, are mobile, and may be held with the hands without a tripod or bar support, even for holes 12 to 20 feet deep, they are seldom used for heavy blasting because the drill bit is small. Ordinary hammer drills use a 1½-inch bit to start a hole, while many piston drills are 2¼ inches in diameter. As the depth occupied by 4 pounds of dynamite in a hammer-drill hole would accommodate 9 pounds in a piston-drill hole, the latter is generally preferred. Some quarrymen, however, believe that the speed of operation of a hammer drill more than compensates for the restricted size of the holes.

Churn drills, or well drills as they are commonly called, have been used very widely during recent years in preparing for primary blasting. They may be driven by steam, gasoline, compressed air, or electricity. The last is most convenient and requires least labor. Churn drills usually are regarded as the best equipment for benches 20 feet or more high. The purpose of drilling is to obtain space for the explosive, consequently the only fair method of comparing costs is to consider drilling, not in terms of cost per foot but rather on the basis of the volume of space obtained. Churn-drill holes are usually about 6 inches in diameter and are as large, or nearly as large, at the bottom as at the top, whereas piston-drill or hammer-drill holes diminish in diameter with increasing depth. Small holes often are sprung with dynamite to give space for the

explosive, a tedious and somewhat dangerous operation, but churn-drill holes seldom require springing.

It is claimed that some improved hammer drills will sink holes to a depth of 30 to 36 feet and will maintain a diameter of 2 inches at the bottom. The volume of drill holes varies as the square of the diameter, therefore a 6-inch churn-drill hole of given depth has nine times the volume of a 2-inch hole of the same depth. Hence, if no springing is employed, nine 2-inch holes are needed to provide space for explosives equal to that supplied by one 6-inch hole. Tripod or hammer-drill holes of shallower depth may maintain a diameter of 2½ inches to the bottom, and about six such holes are equivalent to one churn-drill hole. It is then evident that the small drill competes most keenly with the churn drill in shallower holes, where there is little loss in diameter from top to bottom. Therefore, where springing is not employed the problem of relative cost resolves itself into the question: Is the total cost per foot, including repairs, overhead, interest on investment, and similar charges, six times as great for churn-drill operation as for small drills that bottom with 2½-inch diameter, or nine times as great as for small drills that bottom with 2-inch diameter? The advantage probably lies with small drills for low benches and with churn drills for high benches.

Churn drills are most advantageous where the quarry face is 30 to 100 feet high, although they have been used successfully on benches of not more than 20 feet. As low benches require closer spacing of drill holes and lighter charges smaller drills usually are preferred. In many limestone regions the rock is greatly dissected by erosion, leaving a rugged surface over which it is difficult to move a churn drill, and on which a timber staging is required. Where such difficulties are encountered drilling from the face with piston or hammer drills may be preferable.

Steeply inclined beds separated by open or clay-filled seams present drilling difficulties, for when a churn-drill bit meets a slanting surface it may be diverted, forming a crooked hole in which tools may bind, causing great loss of time, with possible loss of the drill bit and abandonment of the hole. To overcome this difficulty, pieces of rock, wood, or cast iron may be thrown into the hole, so that the drill will pound on them for some time. When the downward progress of the drill is thus retarded it enlarges the hole, particularly by cutting away rock that tends to divert it from its vertical course; thus the hole is straightened. Other methods of overcoming the difficulty are to explode a stick of dynamite in the hole or to pour in concrete, which is allowed to set before drilling is resumed.

In some deposits successive beds may so vary in composition that they must be applied to different uses. Thus, an upper bed may be suitable only for road stone and a lower one for furnace flux or for lime burning. Obviously, such a quarry should not be worked as a single bench and is

not adapted for churn drills unless one or more of the separate benches is at least 20 feet high.

Blasting.—The preliminary shattering of rock in its native bed is known as "primary blasting." It may be done in piston-drill or hammer-drill holes, in chambers, or in deep churn-drill holes. The last method is employed quite generally in quarries where the limestone is used as crushed stone or for the manufacture of cement, but less commonly where it is quarried for lime plants. Where churn-drill blasting is practiced it usually is conducted on a large scale, and a single blast at times supplies stone for several months' handling.

Some quarrymen claim that heavy blasts in churn-drill holes break rock effectively and therefore little secondary blasting is necessary, while advocates of small-hole blasting maintain that more general distribution of the explosive in small holes throughout the rock mass breaks it more completely and less block-hole shooting is necessary than by the churn-drill-hole method. Undoubtedly, different results are obtained in different types of rock. In any case, the amount of secondary blasting depends largely on the quantity of explosive used and the arrangement of drill holes for the primary blast.

Ammonia dynamite is the explosive most commonly used in quarry work, although gelatin dynamite is used in wet holes. Choice of explosives depends somewhat on the use to which the stone is to be put. High-grade explosives may be used where extreme fragmentation is desired—for example, in rock for cement manufacture. In preparing stone for lime burning, for furnace flux, or in any crushed form where fines are undesirable, explosives with a high rate of detonation generally are not used; dynamite of 30 to 40 per cent strength is most satisfactory.

Liquid oxygen (commonly called "L.O.X.") is used in quarry blasting to some extent as a substitute for dynamite. It is safer to handle than ordinary explosives and because it evaporates rapidly there is no danger from misfires. Cartridges of absorbent paper filled with lampblack alone or mixed with ground cork are submerged in liquid oxygen until saturated, then placed in drill holes with as little delay as possible, tamped with sand, and fired with an electric detonator. The L.O.X. method of blasting is not feasible, except where quarries are near a liquid-oxygen-manufacturing plant or where companies are large enough to justify manufacture of their own supplies of liquid oxygen.

Piston-drill and hammer-drill holes usually are closely spaced because they can accommodate only small charges. In some quarries where small drills are used the stone is removed from low benches drilled from the top; in others the holes are drilled from the face horizontally or inclined. In "snake-hole" blasting, where holes are at the base of the bench, "springing" is commonly employed to obtain a chamber large enough to hold an effective charge. In springing, 1 to 4 sticks of dynamite may be used

in each hole for a first charge, 5 to 8 for a second, 10 to 20 for a third, and 20 to 30 for a fourth. The holes may be sprung more than four times, but it is not advisable to make the springing charges very heavy, for cracks may be opened, which will decrease the effectiveness of the final charge. For the final charge the chambers and part of the drill holes are completely filled with explosive, the remainder of the holes being tamped with clay or rock dust. The charges are fired simultaneously by electricity.

Another blasting method, known in the East as "tunnel," in the Middle West as "gopher-hole," and on the Pacific coast as "coyote-hole" blasting consists of firing large charges in tunnels driven into the quarry face at the floor level. The method is simply snake-hole blasting on a large scale. The tunnel or drift usually is 3 to 4 feet wide and 4 feet high. An entry is driven 40 or 50 feet, then right and left cross headings are driven at right angles to the main leg, thus making a T-shaped opening. All the dynamite is placed in the cross headings and none in the main leg. The intersection of the legs and at least half of the main leg may be filled with lean concrete, or the passages may be blocked by rough arches of small boulders. The charges are wired in parallel and fired, preferably by a power current. Trinitrotoluene detonating fuse, which is described later, may be used to connect the explosive-filled chambers. This method is best-adapted for quarrying a high face where the strata are irregular or conditions make it difficult to operate cable drills.

An important feature of churn-drill work in deep quarries is the substitution of a single bench for a series of low benches. Disadvantages of multiple-bench quarrying that may be obviated by using a churn drill are: (1) Danger to workmen from rock fragments falling from one bench to another; (2) loss in productive capacity where men watch for falls of rock from the bench above; (3) loss of time and danger of accident where workmen climb ladders and move explosives and equipment from bench to bench; and (4) unduly complicated systems of transporting stone from different levels.

A single row of churn-drill holes usually is preferred where the quarry face is 50 or more feet high. Where it is 20 to 30 feet high two to five rows of holes may be shot at once. The burden (distance of hole from face) and spacing (distance from hole to hole in the row) may vary considerably in different types of stone. An operator may begin with close spacing and increase it gradually until the maximum spacing that will effectively shatter the rock is attained. In average limestone worked from a quarry having a 35- to 40-foot face the spacing is about 10 to 12 feet and the burden 12 to 15 feet. Spacing and burden increase with increasing depth of holes but rarely exceed 20 to 25 feet for the deepest holes.

Some blasting experts recommend that where more than one row of holes is shot at once the back rows should contain at least 10 per cent more of explosive than the front row. A shorter burden for the back rows also is recommended, and holes in adjacent rows are staggered.

In approximately flat-lying beds an open-bed plane sometimes may be utilized to form the quarry floor; it is then comparatively easy to blast the rock to the base of the ledge. Where there is no open-bed seam or where the rock is steeply inclined and there is no joint that may be utilized as a floor seam, clearing the rock at the toe is more difficult. A common mistake in drilling is to sink the hole not far enough below the quarry-floor level. One blasting expert advises a depth of 5 feet below grade in solid limestone.

The effects of a charge may be reduced greatly or lost entirely if the drill hole penetrates a mud seam or clay pocket. If open seams occur in any definite system or exhibit any degree of regularity, it may be possible to calculate their position at depth and thus avoid them in drilling. Where large, open, or clay-filled spaces are encountered in drilling it generally is advisable to abandon the hole. Where the seam is of moderate size, however, the drill hole may be utilized if the explosive is kept away from the seam. This may be done by filling the hole with stemming from a point 3 or 4 feet below the seam to one 3 or 4 feet above it. Sometimes it is considered better to concrete the cavity and redrill it when the cement has set.

At many quarries determination of the amount of explosive to use for the entire charge or for each drill hole is mere guesswork. Neither high blasting efficiency nor consistent improvement in blasting methods is to be expected unless the charge is regulated according to the estimated tonnage of rock to be moved. The tonnage is determined by multiplying the burden by the spacing by the depth to ascertain the number of cubic feet of rock; this is multiplied by the weight of 1 cubic foot of limestone (usually about 160 pounds) and divided by 2,000. Thus, if the burden is 15 feet, the spacing 12, and the depth 50, the number of short tons of rock to be moved by the explosive in each drill hole is $\frac{15 \times 12 \times 50 \times 160}{2,000} =$ 720 tons. In average quarries 1 pound of 40 per cent ammonia dynamite shatters 3 to 6 tons of rock, depending on its toughness. A first charge may be estimated on an average basis, say a pound for every 4 tons. For the drill hole above mentioned 180 pounds of dynamite would constitute a reasonable charge. Results will indicate how correctly a charge has been estimated. If the rock is not broken enough, the next charge may be calculated on the basis of 1 pound for every 3½ tons; if too greatly shattered the charge may be decreased to a ratio of 1 pound for every 5 tons.

Best results are obtained not only by varying the charge but by changing the spacing or burden of drill holes. Where the rock is brittle and is pulverized close to the explosive charge, though not broken enough at a distance, it may be advisable to use smaller drills and thus distribute the charge more generally throughout the rock mass. In the best-regulated quarries superintendents keep accurate blasting records, which show for each large shot the number and depth of holes, spacing, burden, kind and weight of explosive in each hole, tonnage of rock moved, and condition of fragmentation. Such records are of inestimable value in calculating other blasts.

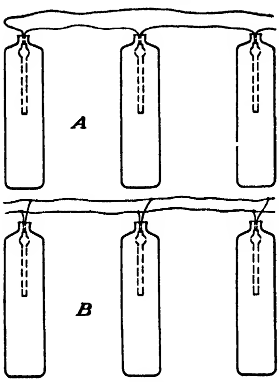

FIG. 70.—Method of connecting wires for firing dynamite. *A*, wiring in series; *B*, wiring in parallel.

The charge is modified somewhat to suit the loading method. For hand loading it is adjusted to throw the rock out in a thin sheet. For steam-shovel loading, however, the rock fragments should lie in a steep ridge near the quarry face. In quarries with low faces where several rows of holes are shot at one time to provide stone for steam-shovel loading, a method known as "buffer" or "blanket" shooting sometimes is employed. Part of the broken stone from the previous blast is left against the face to offer resistance or confinement to the charge, thus assuring better fragmentation and preventing fragments from hurtling over the quarry floor and damaging or burying tracks. The buffer method is not used where faces are more than 50 feet high.

In practically all primary shots in quarries the explosives in various holes are fired simultaneously. If electric detonators are used there are two general methods of connecting wires when several shots are to be fired at once. These methods are known as "series connection" and "parallel" or "multiple connection." The distinguishing characteristics of each are shown in figure 70. As a rule, shots should be connected in series when they are to be discharged by hand or by spring-operated magneto generators, because these generators do not have enough current capacity to fire in multiple. Where the shots are discharged by current taken from a power circuit, either series or multiple connection may be used. If shots are connected in series, a minimum potential of about 1½ volts per shot will be required if the source of potential is constant; if it is variable, as is the case when hand- or spring-operated magneto generators are used, a somewhat larger voltage is desirable. The source of power used to fire shots connected in series should be capable of supplying at least 1¼ amperes. When shots are connected in parallel the source of power should supply about an ampere for every shot to be fired and should

be capable of supplying enough potential to force the total current through the connecting conductors. A third method, sometimes employed where many holes are fired at once, is a combination of the above methods and may be termed a "multiple-series" or "parallel-series" connection. Holes are connected in series in small groups, and the groups are connected in parallel. Each subseries must have the same resistance.

As a safety precaution to avoid misfires each electric detonator, as well as the entire circuit, usually is tested with a galvanometer. Strong detonators are used, and as a rule two are placed in each charge. For heavy blasting in deep churn-drill holes detonators are distributed at intervals throughout the length of the charge.

A method of firing gradually being adopted more widely involves the use of the detonating fuse known in the trade as "Cordeau." It consists of a lead tube carefully drawn to uniform size and filled with trinitrotoluene. The fuse extends to the bottom of each blast hole. After the holes are loaded and tamped a main line of fuse is placed on the surface and attached to the branches from each hole. No detonators are placed in the holes; one detonator is attached to the main line, and when fired the explosive wave flashes along the main line and into each drill hole. As the rate of detonation of the fuse is very high all charges are fired at virtually the same time. Greater safety and increased efficiency are advantages of the detonating fuse. Trinitrotoluene can not be exploded by friction, fire, or ordinary shock but requires the shock of a detonator; it is therefore safe to handle and store. When a fuse is used detonators are not required in the holes, and the danger from accident during loading is greatly reduced.

The primary shot ordinarily is insufficient to break rock to small enough sizes for loading, and secondary blasting must be employed. This process is known locally as "blistering" or "bulldozing." Two methods are in common use. The "mud-capping," or "adobe" method consists of placing a stick of dynamite with a fuse attached on the surface of the rock to be broken and covering it with a mass of clay, which tends to confine and direct the explosion toward the rock. This method usually is inefficient and expensive. By the second method, known as "blockholing," or "pop-shooting," holes several inches deep are drilled in the blocks with hammer drills, and a stick, or part of a stick, of dynamite is placed in each hole. Rock dust or clay may be used for stemming. A number of shots are thus prepared, the fuses lighted, and the blasts discharged in rapid succession. This method is regarded as at least ten times more effective than mud-capping for a given quantity of explosive.

Loading.—Loading broken stone into cars for removal from the pit is usually the largest single item of quarry expense. Two general methods are followed—hand loading and power-shovel loading. Hand loading is commonly employed at quarries supplying lime plants or providing flux

for furnaces. For such uses, chemical purity is demanded, and hand methods afford a means of selective loading with rejection of siliceous or otherwise impure fragments. Furthermore, lump stone, with a minimum of fines, is desired for both these uses, and the hand loader can sledge the larger masses with a minimum production of fines. The small outlay required for loading equipment and the uninterrupted flow of stone to kilns, furnaces, or crushers are other advantages.

In quarries producing aggregate, road stone, or ballast where chemical composition is unimportant and where large tonnages are involved a power shovel is generally used. Some years ago nearly all power shovels were steam-driven, but both compressed air and electric shovels are now in use, the latter type having greatly increased in numbers during recent

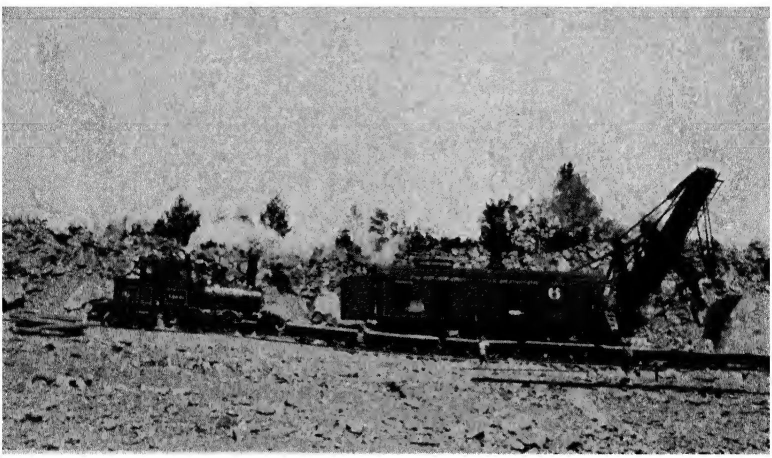

FIG. 71.—A large railroad-type shovel loading limestone into cars hauled by steam locomotive.

years. The size of shovel is governed by the volume of material to be handled. For a daily output of 150 to 300 tons of stone small tractor shovels with 3/4- to 1 1/4-yard dippers are suitable. Caterpillar tractors offer special facilities for rapid moving or for working on a soft bottom. For larger quarries heavier shovels are used. For some large open-pit operations shovels with dippers capable of handling 5 to 10 tons are employed. A mechanical shovel can handle rock fragments weighing several hundred pounds or even more than 1 ton. If a primary blast breaks the rock moderately well, very little secondary blasting may be required, whereas in hand loading much secondary blasting and a great deal of laborious hand sledging are necessary.

The tonnage per man is increased greatly by using power shovels. Records of a number of quarries a few years ago show an average daily output of 112 tons per man (pitmen and shovel men only) by power shovel, contrasted with a daily average of 16 tons per hand loader.

The power shovel has some disadvantages. It lacks the ability to sort materials and, as it handles large fragments, requires accessory crushing and screening equipment. The large investment involved makes it more profitable to employ hand-loading methods at many small quarries, but for large enterprises power-shovel equipment is indispensable. A typical loading operation is shown in figure 71.

Haulage.—Haulage involves the motive power and equipment required to convey stone from the loading place at the quarry face to some point outside the quarry, where it is transshipped, crushed, or otherwise treated. Ordinary transportation equipment may be divided into three classes—trackage, cars, and haulage systems. The arrangement of tracks for quarry cars depends on the loading method and the size and shape of the quarry opening. For hand loading it is desirable for maintenance of a maximum output to have many working places, each with independent trackage from the main line. A convenient system for a quarry with a

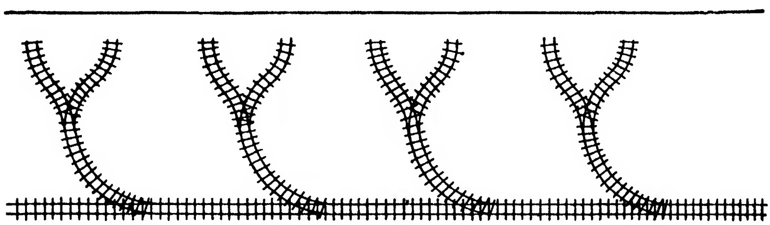

FIG. 72.—Track arrangement for hand loading at a long quarry face.

long face consists of a main line paralleling the face and a series of spurs each ending in a Y running from the main line to the face, as shown in figure 72. Thus, space is provided on one branch for an empty car that may be loaded while the car already filled is conveyed from the other branch of the Y to the main track. At some plants, tracks converge like the spokes of a wheel from the quarry face to the point where the stone leaves the quarry. Thus cars may be placed at many points along the face, and those loaded at each working place may be moved independently. Such a track arrangement is shown in figure 73.

For power-shovel loading two different systems are followed, according to the width of the working face. Where it is wide enough to permit necessary movement of cars, the car track parallels the face; thus cars may be moved along and filled in succession until a train is loaded. This system, which is followed in virtually all large quarries, is illustrated in figure 71.

For mechanical shovel loading at quarries having a narrow face the track usually runs directly toward the face and ends in a Y, each branch of which accommodates two or more cars. While the shovel loads stone into cars on one branch, loaded cars may be shifted from the other branch

and replaced by empties. This arrangement permits almost continuous operation. Careful grading of the quarry floor that will permit gravity movement of loaded cars from the face is an advantage.

At some point in the quarry the method of haulage usually changes. In pit quarries it is at the foot of the incline up which cars are hauled to the quarry bank. At shelf quarries it is the place where cars are assembled for removal in trains. Cars may be removed from shelf quarries over tracks that are level or have only moderate grades. Transportation from pit quarries may involve the use of inclined tracks, many of which are so steep cable haulage is required. On short inclines each car usually is handled independently, but on long inclines a car may be attached to

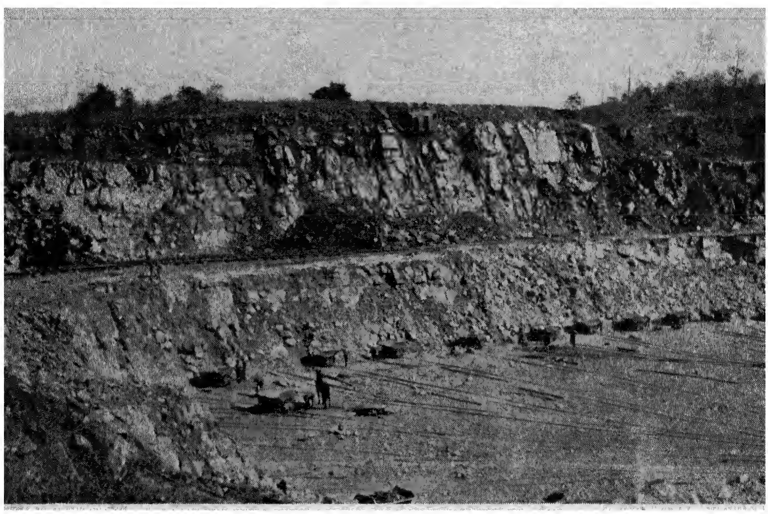

FIG. 73.—A limestone quarry worked in two benches; the stone is loaded by hand.

each end of a long cable, the empty being returned while the loaded car is elevated. The weight of the empty car thus assists in elevating the loaded one, and both time and power are conserved. Such a system may have double tracks the entire length of the incline or a single track below the center switch and a two- or three-rail track above it. Elevation also may be attained by back-switching on a zigzag track. The gage of quarry tracks is generally 24 to 42 inches, although standard railroad gage, 56½ inches, is occasionally used.

The weight of steel required for tracks depends on the method of haulage and size of cars. For 2- to 3-ton cars hauled by animals or moved by gravity, steel weighing 16 pounds to the yard may serve, but a 20- or 25-pound rail is better. For cars or locomotives weighing 7 to 10 tons a minimum weight of 35 to 40 pounds a yard is recommended.

Centrifugal force tends to overturn or derail cars on curves if the outer rail is not elevated adequately. The following table gives the correct elevation for the outer rail.

PROPER ELEVATION OF OUTER RAIL ON CURVES OF DIFFERENT RADII FOR A SPEED OF 6 MILES AN HOUR ON A 30-INCH TRACK

Radius of curve, feet	Elevation, inches	Radius of curve, feet	Elevation, inches
40	1¾	100	¾
50	1½	150	½
60	1¼	200	⅜
80	1		

The elevation should vary directly with the width of gage and as the square of the velocity.

Quarry cars are of many different types and sizes. For hand loading, low cars of 2 to 2½ tons capacity are most popular, and open-side cars offer some advantages. For power-shovel loading larger and stronger cars are required. Side-dump cars are the most common, though end-dump cars sometimes are used. Although hand-loaded cars should be low, cars for steam-shovel work should be high, as a high position gives a better angle of discharge from the shovel dipper.

Quarry cars of many varieties are now in use. Opinions differ widely among operators as to the advisability of standardizing cars and reducing the number of sizes and styles employed. Many approve such standardization, particularly where loading is by contract, as cars of uniform size and height obviate a possible cause of complaint by loaders and simplify the fixing of contract prices. On the other hand, many operators see little prospect of standardization because of the great differences in quarry conditions, sizes of crushers, and types of haulage.

Various types of motive power are employed. Gravity is the most economical source and is employed in many quarries where conditions favor use. Careful adjustment of grades makes car movement in some quarries largely automatic. A favorite method is to maintain a gentle down grade from the face to the incline, permitting loaded cars to proceed by gravity. The empties may be hauled back by horses or mules. Many operators prefer animal power for short hauls within a quarry or mine, especially where stone is hand-loaded, but there is a growing tendency to replace it with smaller types of electric or gasoline locomotives. For larger operations, particularly where loading is mechanical and the distance exceeds 500 feet, locomotive haulage generally is employed. Steam locomotives or "dinkeys" are widely used and favorably regarded by many. They may haul trains of 5 to 20 cars. Other operators prefer gasoline or electric locomotives. Some are small and able to handle 1 to

3 cars only, although some of the newer gasoline locomotives will haul 10 to 15 cars. Some large quarries use the Woodford central-control electric third-rail system. The track is divided into sections, with an independent current for each; thus cars on different sections are subject to independent control. Movements of cars are controlled from a central tower.

Cable-and-drum haulage is commonly employed on inclines. The so-called "ground hog" or "barney car" is used on some inclines to take the place of cable attachment to each individual car. A heavy buffer mounted on four wheels and attached to the cable operates on a narrow-gage track between the rails of the car track. On the level or nearly level floor some distance from the foot of the incline the narrow-gage track runs into a depression below the car-track level. When the cable is out the buffer rests in this depression. Loaded cars pass along the track over the excavation, and as the cable winds on the drum, the buffer comes up behind the car and pushes it up the incline. Usually only one car is taken up at a time.

Some quarries maintain smooth roadways with moderate grades and use truck haulage, eliminating the need of tracks. The crushing plant may be situated on the quarry floor, and a belt conveyor or bucket elevator used to carry the crushed stone to the surface. Among the more unusual means of elevating stone from pit quarries are derricks, overhead cableways, and traveling cranes.

Crushing.—At quarries where hand-loaded stone is used for lime burning or furnace flux crushers may not be needed. However, crushing equipment is an important adjunct of nearly all quarries producing stone for concrete aggregate, road building, or railroad ballast. At small quarries stone may be loaded by hand and reduced with portable crushers. It is generally conceded that it is cheaper to break stone by crushing than by the use of explosives.

The main types of crushers in general use are the gyratory crusher, the jaw crusher, double rolls, single rolls, cone, and disk. Details of construction and operation may be obtained from handbooks on milling or from manufacturers' catalogs. Gyratory or jaw crushers are used in nearly all hard-rock quarries. Rolls provided with blunt teeth give satisfactory service where the stone is not exceptionally hard. They may be operated in pairs (the stone being crushed between them), or used singly, a baffle plate being substituted for the second roll. Their wide, hopperlike mouths adapt them for large fragments. Rolls are in common use at quarries which supply limestone to cement plants.

Crusher size is governed to some extent by the size of stone fragments that can be loaded and transported. Where stone is loaded with power shovels, crushers at the best-regulated quarries are large enough to accommodate any stone fragment the shovel dipper can handle. Some

crushers are adapted in size to handle any block that will pass through the dipper, and shovel runners are instructed to load no fragments of larger size. An undersize crusher is a serious handicap, as it retards all operations, demands excessive secondary blasting, and involves heavy repair charges. Some quarrymen prefer oversize crushers, for while first cost and power charges may be high, maintenance expense is usually low, and there are few or no delays with jammed blocks.

Where stone is prepared for lime manufacture or for aggregate, road stone, or ballast a minimum percentage of fines is desired. Opinions differ as to the type of crusher that will give the least fines. It is a generally recognized principle that "choke feeding"—keeping the crusher filled to capacity—tends to give more fines than when stone is fed gradually, and not faster than the crusher can handle it. To avoid choke feeding an apron feed that supplies stone to the crusher in a steady uniform stream may be employed. At quarries of cement plants conditions are quite the reverse, for as the stone is pulverized before use a maximum percentage of crusher fines is desired.

Screening.—Crushed-stone fragments are assorted by size with some form of screen. For separation of the larger sizes of limestone used for lime burning or furnace flux an inclined railroad rail or bar grizzly with 3½- to 5-inch spacing sometimes is used. The rotary screen or trommel is the most widely employed of all types at stone-crushing plants. Screening equipment has undergone many recent changes. The most noteworthy change in coarse sizing or scalping is the introduction of rotary disks, such as the cataract grizzly and the multiroll sizer, as substitutes for trommels. They consist of a series of rotating disks with spaces between them through which the finer stone drops. As the oversize stone descends, it successively encounters disks that rotate at greater speeds, preventing binding and grinding. The advantages claimed are long wear, absence of vibration, and minimum grinding and breaking of the stone, as there is no cascading action on the screen. Another change worthy of mention is increasing use of vibrating screens for finer sizes.

Washing.—The demand for clean stone with a minimum of fines has led to the addition of washing equipment at many plants. Washing is particularly desirable at quarries where clay seams are present, for there is no other way of easily separating adhesive clay from stone. Washing is accomplished by directing a jet of water on the stone as it cascades in a trommel, or as it passes over rotary disks or vibrating screens.

Elevating and Conveying.—Pan conveyors or bucket elevators may be used to raise stone from crushers to screens or to storage. Belt conveyors are serviceable if the angle of elevation is low, and stone is conveyed to storage and from storage to shipping equipment with them at many plants. Cascading of stone from high elevations is to be avoided,

particularly if the stone is soft, as undesirable quantities of fines are thus produced.

Storage of Stone.—Both rate of production and market demands may fluctuate. In northern climates winter weather may interrupt and curtail production, and in numerous locations protractd rains may cause suspension of work in open quarries. Unfavorable quarry conditions, broken equipment, or other unforeseen difficulties may contribute to these interruptions. On the other hand, demands for the product may be small at times, particularly in winter, or rush orders may call for deliveries of stone at a rate much in excess of quarry capacity. Many operators find it desirable, therefore, to maintain stone in storage to supply unusual needs or provide for the demands of regular customers when for one reason or another the crusher plant is idle. Storage capacity also permits operation of quarries when sales have diminished. At most plants, storage facilities of some kind are necessary because delivery of stone directly from crusher to truck, railroad car, or vessel is not feasible. Separate storage must be maintained for each of the regular screen sizes. Some convenient storage systems consist of bins or piles to which stone is carried by belt conveyors and from which it is loaded directly to trucks or cars through chutes, or to vessels by belt conveyors. The latter are carried in tunnels beneath the storage piles. Speedy mechanical handling with a minimum of labor is the first requisite of an efficient storage system.

Fine Grinding.—As noted in the section on uses, much limestone is employed in ground form. Because most of the products are too low-priced to justify the cost of drying a slurry or pulp, dry-grinding processes generally are used. A variety of grinding mills is in use. Some mills are of the rollhead type, working like pestle and mortar. Roller mills of various types, as well as impact, beater, or swinging-hammer mills, are employed. Ball or pebble mills are preferred by many for very fine-grained products. Extremely fine subdivision is attained by means of revolving-plate machines, such as the colloid mill. In pulverizing limestone for paints or ceramic wares in which the iron content must be very low, flint pebbles rather than steel balls are used. For successful dry grinding the moisture content of the stone must be low, hence usually it is passed through a rotary drier. Dry products generally are classified according to size by air separation, although vibrating screens give good service, particularly for sizes coarser than 50-mesh.

Removal of finished material from the system as soon as it is produced is a notable recent advance in fine grinding. A good example of this process is to be found in the air-swept tube mill, where the finer sizes are carried away as soon as formed. Grinding efficiency is increased thereby because the cushioning effect of fine particles is greatly reduced. Closed-circuit grinding is in general use, the coarser particles being returned to

the system for further reduction. It has recently been found advantageous to carry high-circulating loads in ball mills. Very finely divided material, known as whiting substitute or marble flour, is prepared by wet or dry processes described previously. (See page 383.)

Operating Costs.—Quarry conditions are so variable that both the individual items and the total cost are quite diverse in different quarries. Therefore, it is difficult to estimate costs definitely for a particular operation, but average costs may have some value. Thoenen[69] obtained a cost of 67 cents a ton as an average for 30 open-pit limestone quarries in various parts of the country. For an average quarry operating on a large scale this total might be distributed as follows: Stripping, 6 cents; drilling, 9.5 cents; explosives, 7.5 cents; loading (hand), 22 cents; mucking, 6 cents; haulage, 5 cents; repairs, taxes, and similar charges, 5.5 cents; interest and amortization, 5.5 cents; total, 67 cents. If a power shovel is used the direct-loading cost in general would be much less than 22 cents, but with interest on investment, together with additional crushing expense, the total would probably differ little from the hand-loading cost. It must be emphasized that some of these items will be much higher and some much lower under the peculiar conditions of individual quarries. A cost analysis by Thoenen[70] of 110 limestone quarries grouped according to size and equipment show direct quarrying and crushing costs ranging from 35 to 95 cents a ton.

Underground Mining Methods.—Limestone is obtained chiefly from open-pit quarries. Where the overburden is thin, quarrying by deep-hole blasting and power-shovel loading is the cheapest method of obtaining stone. However, conditions do not always favor open-pit work, and more and more operators are finding it advantageous to employ underground methods. The chief factors tending toward use of the mining method are (1) a heavy overburden of soil or inferior rock which blankets a flat-lying deposit of good limestone, (2) inclination of the beds of serviceable stone that demands too great an extension of the pit along the strike or outcrop and results in an increasing overburden as the pit is enlarged in the direction of dip, and (3) the necessity for working at increasing depths as surface deposits are exhausted. Limestone is too low in price to justify the expense of mine timbering, except possibly in shafts or entries, hence mining is successful only where the rock is strong and massive enough to permit maintenance of safe roofs in drifts and chambers, with supporting pillars spaced not less than 25 or 30 feet apart.

The principal advantages of underground work are avoidance of stripping, freedom from contamination by overburden, and protection

[69] Thoenen, J. R., Underground Limestone Mining. Bur. of Mines Bull. 262, 1926, p. 94.

[70] Thoenen, J. R., Study of Quarry Costs. Bur. of Mines Rept. of Investigations 2911, 1929, p. 2.

to laborers from snow, ice, and rain. Some disadvantages are to be noted. Drilling and blasting are more costly than in open-pit work, the proportion of fines is increased, and 20 to 25 per cent of the rock is unused, as it must remain in the form of pillars for roof support.

Thoenen[71] found that the average cost of mining limestone in the United States was about 96.4 cents a ton and therefore exceeded the average cost of quarrying by about 30 cents a ton. Hence, under average conditions, if the stripping cost exceeds 30 cents a ton of rock uncovered, it would be cheaper to mine. This rule, however, must not be taken too literally, for conditions may not favor underground methods. No set rule governing a choice between underground and open-pit work can be given; each operation is an individual problem that must be considered on its merits. Weight must be given conditions of roof, strength and soundness of rock, and presence of floor and roof seams, and to other conditions on which successful underground work depends.

In 1925 at least 64 underground limestone mines were operating in the United States, and new ones have been developed since that date. Some are very extensive; one mine in Pennsylvania produces normally about 3,500 tons of stone a day.

Most mines are of the adit or tunnel type; that is, the entrance is an approximately horizontal tunnel from an outcrop or from the side of an open pit. A few mines are of the vertical or inclined-shaft type. Several different methods of development are followed. The simplest is the single-breast stope, which is best-adapted to thin, flat beds. The tunnel is worked out in all directions on a constantly enlarged circumference, and pillars for roof support are left at irregular intervals. A more systematic method is known as room-and-pillar mining. Square or rib pillars are left in regular rows, with rooms and haulageways between. Tunnels may be advanced by carrying a breast stope just below the roof, thus forming a bench in which holes for blasting are drilled vertically to the floor level. Another method is to carry the breast stope at the floor level and to drill upward in the so-called back stope. Many modifications of the methods are followed. Thoenen gives details of underground mining in the bulletin already mentioned.

Modification of Method According to Use.—The major quarry processes, from stripping the rock surface through all stages of preparation to storage of the finished product, have been covered in preceding pages. Although they apply in general to all industries producing crushed and broken limestone, quarry methods differ somewhat according to the use for which the stone is prepared. Outstanding differences in method for the chief subdivisions of the limestone industry are discussed briefly in following paragraphs.

[71] Thoenen, J. R., Underground Limestone Mining. Bur. of Mines Bull. 262, 1926, p. 10.

Methods at Cement-plant Quarries.—Cement can be manufactured profitably only on a fairly large scale; hence, quarries that supply cement mills with limestone are, as a rule, well-equipped for mass production. Blasting is usually in deep churn-drill holes, and heavy charges are used because maximum breakage of rock is desired. Clean stripping of overburden is unnecessary if the cover consists of suitable clay, because clay must be added to limestone to make a satisfactory mixture. To maintain a proper proportion of lime, alumina, and silica and to keep iron and magnesia within required limits, chemical control is required. If the rock is variable from point to point laterally it is usually desirable to work a long face to equalize the composition. At some quarries cars loaded at successive points along the face are unloaded in regular rotation. If a quarry has high-calcium stone at one end and low-calcium at the other, power shovels are operated simultaneously at both ends, and cars from the two loading places dumped alternately. If successive horizontal beds vary in composition from top to bottom of a high working face, blasting the full height of the face as a single bench also tends to mix stone from different ledges. Uniform distribution throughout the length of a large storage bin assists in equalizing composition.

Methods at Lime-plant Quarries.—Most of the lime now manufactured in the United States is calcined in shaft kilns. Stone under 4 inches in size is undesirable, because fines retard draft. Therefore, the object in blasting is not to attain maximum fragmentation, as in cement-plant quarries, but rather to shatter the rock with a minimum production of fines. Moderate charges are used, and the explosive may be of lower grade than that employed at cement-plant quarries, even though more secondary blasting is required. Many operators prefer hand-loading methods, because hand sledging produces less fines than mechanical crushing. The impurity in the stone should be preferably under 2 or 3 per cent, and hand loading has the added advantage of permitting selection according to quality. The necessity for purity in the stone demands clean stripping of overburden. If clay pockets or seams are present some siliceous impurity will be mixed with the broken stone. If hand-loading methods are followed clay and fines are removed to the dump as a mucking process. If mechanical shovels are used screening is necessary, and some plants have both screening and washing equipment.

Methods at Fluxing-stone Quarries.—Methods at quarries producing furnace flux are similar to those at lime plants, because for both uses lump stone of high purity is demanded. However, many of the fluxing-stone quarries are so large that mechanical loading is regarded as a necessity. Where power shovels are used they must be followed by crushers and screens, and washing equipment is not uncommon. Where hand-loading methods are employed forks often are used to load the smaller fragments to eliminate both fines and the sand or clay associated with them.

Methods at Crushed-stone Quarries.—Production of road stone, concrete aggregate, and railroad ballast has one feature in common with the quarrying of fluxing stone and raw material for lime manufacture, namely, the undesirability of fines, as the smaller sizes and dust usually are most difficult to market. Here the similarity ends. For the crushed-stone industries such physical properties of the stone as hardness, toughness, and porosity have much greater importance than chemical composition. This is evident from the fact that rocks as diverse in composition as granite and limestone are used in identical ways as crushed stone. Therefore, in quarry processes little or no attention is given to variations in chemical composition. Except at small local quarries, mechanical handling is the rule because the product commands so low a price that quantity output requiring a minimum of labor is necessary if the project is to be an economic success.

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CHAPTER XVIII

CRUSHED AND BROKEN STONE OTHER THAN LIMESTONE

GENERAL FEATURES

Although limestone is by far the largest source of crushed and broken stone, other varieties are used extensively in many places. The chief types so used are basalt (trap), granite, and sandstone. In statistical compilations of the United States Bureau of Mines a miscellaneous group includes all rocks not definitely identified with the major varieties. Trap is a commercial term comprising fine-grained, basic igneous rocks, such as diabase and basalt, but is somewhat indefinite in its application, as it includes various rocks of uncertain composition. The term granite, as used commercially, includes, in addition to true granite, syenite, diorite, gabbro, and other medium- or coarse-grained igneous rocks. Sandstone includes the highly indurated varieties known as quartzites. Miscellaneous stone includes light-colored volcanic rocks (rhyolite, trachyte, or tuff), schists, boulders from river beds, slate, serpentine, flint, and many other diverse sorts.

USES

Unlike limestones, most of the stones in these four groups are chemically inert and therefore have limited use outside the main fields of application, namely, as concrete aggregate, road material, and railroad ballast. Any of them may be used for riprap where the need exists. Special uses may be briefly mentioned.

Various types of igneous rock are used as roofing gravel or as granules for surfacing prepared roofing. More than 117,500 tons of granules made of stone other than slate were sold in 1930. Their value at the mill was about $727,000. Another important special application is the utilization of quartzite for the manufacture of silica brick or as furnace lining or furnace sand. Quartzite suitable for such uses is known as ganister. For its principal use it is ground to a powder, mixed with about 2 per cent lime as a binder, molded into bricks, and calcined. Silica brick are classed as refractories and used extensively in lining coke ovens and metallurgical furnaces. About 1,000,000 tons of ganister were produced in 1929, but owing to furnace inactivity production fell to about 120,000 tons in 1932. Production is centered chiefly in Pennsylvania and Wisconsin, with a smaller output in Alabama, Arizona, California, Colorado, Illinois, Maryland, Minnesota, Montana, Ohio, South Dakota, Tennessee, Washington, and West Virginia.

Outlets for waste stone, comprising varieties other than limestone, are limited. Waste trap-rock and granite screenings are employed for road surfacing and to a limited extent for filler in asphalt and other products. Granite chips are used to face concrete blocks to make them resemble stone and to give color to artificial stone and terrazzo. Sandstone fines are utilized as building, paving, and furnace and glass sand, and to some extent as asphalt filler. Coarser sizes are sold as roofing granules. Sandstone screenings may be used for the manufacture of sand-lime brick, and screenings of various miscellaneous stones in the same way as granite or trap. Serpentine chips are sold for terrazzo flooring material.

GENERAL DISTRIBUTION AND VALUE

Igneous rocks are most abundant in rugged territory traversed by few roads or railroads and remote from large centers of population. Hence, the largest areas are those least used. Chief developments are in outcrops, sometimes isolated and comparatively limited in extent, near large cities.

Granites and other coarse-grained igneous rocks are utilized extensively in New England and throughout other States traversed by the Appalachian Mountains, as well as in Wisconsin and California. The finer-grained, dark igneous rocks (basalt) are used extensively in Connecticut, Massachusetts, New Jersey, New York, Pennsylvania, Washington, and California. The fine-grained, light-colored igneous rocks (trachyte, andesite, rhyolite, and tuff) are confined principally to the Rocky Mountain and Western States, where vulcanism was much more recent than in middle-western and eastern territory. More than half the miscellaneous stone is reported from California. Other important producers west of the Mississippi River are, Arizona, Nevada, Colorado, Texas, and Arkansas. The principal output in the East is from Massachusetts and Pennsylvania.

The chief centers of production of crushed sandstone are in California, New York, Pennsylvania, South Dakota, and Washington. Sandstone is used extensively for riprap in Oregon and Missouri.

The tonnage and value of production of the major groups by States are shown in following tables compiled by the United States Bureau of Mines. Figures for 1930 are given, as they are probably more typical than those of later years.

CRUSHED AND BROKEN GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1930, BY STATES AND USES

State	Riprap		Crushed stone: Concrete and road metal		Crushed stone: Railroad ballast		Other uses	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Arizona	18,010	$ 6,476	25,000	$ 25,000	*	*		
California	66,320	19,700	696,420	591,099	257,100	$ 137,465	2,147,670	$801,301
Colorado	*	*	*	*	*	*		
Connecticut	19,630	12,538	5,110	5,847	....	....	*	*
Delaware	*		*	*				
Georgia	31,330	24,066	279,450	274,255	*	*		
Maine	450	1,072	29,030	53,093	....	....	2,000	338
Maryland	6,000	9,000	103,340	190,854	27,500	53,756		
Massachusetts	3,520	3,998	577,970	890,827	....	....	10,330	16,467
Minnesota	2,130	710	*	*				
Missouri	*	*	*	*				
Montana	3,570	1,936						
New Hampshire	10,190	5,528	39,200	64,157	....	....	*	*
New Jersey	....	....	*	*				
New York	*	*	64,890	63,194	137,170	196,294	*	*
North Carolina	*	*	710,450	906,063	213,540	219,724	6,850	43,680
Oklahoma	1,650	959	5,480	3,887	1,470	1,484		
Pennsylvania	....	....	60,420	81,420	50,000	54,000	390	1,000
Rhode Island	*	*	54,020	75,816	2,410	4,159	*	*
South Carolina	8,040	10,334	1,223,440	1,610,087	110,690	84,396	1,590	1,902
South Dakota	....	....	*	*	....	....	*	*
Texas	....	....	....	....	....	....	*	*
Utah	*	*						
Vermont	....	....	36,860	38,450				
Virginia	*	*	210,460	280,100	*	*		
Washington	15,800	8,781	38,830	43,692				
Wisconsin	245,660	225,501	140,590	242,369	....	....	58,160	57,997
Undistributed	102,900	120,385	177,760	271,828	660,550	526,018	15,830	25,308
	535,200	$450,984	4,478,720	$5,712,038	1,460,430	$1,277,296	2,235,940†	$882,010†

* Included under Undistributed.
† Exclusive of 6,880 tons of Durax blocks, valued at $65,983, made in Massachusetts, North Carolina, and Wisconsin.

CRUSHED AND BROKEN SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1930, BY STATES AND USES

State	Refractory stone (ganister)		Riprap		Crushed stone				Other uses	
					Concrete and road metal		Railroad ballast			
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Alabama	25,280	$ 27,441								
Arizona	......	......	*	*						
Arkansas	......	......	......	......	127,400	$ 176,101				
California	7,500	20,000	26,420	$ 60,589	724,460	625,217	51,950	$ 52,444	150	$ 1,800
Colorado	17,640	26,499	*	*	*	*				
Connecticut	......	......	*	*	*	*				
Illinois	440	2,437	......	......	51,470	27,371	......	......	200	400
Kansas	......	......	......	......	*	*				
Kentucky	......	......	*	*	*	*				
Maryland	9,770	13,071	......	......	16,590	24,879	......	......	*	*
Massachusetts	......	......	......	......	*	*				
Michigan	......	......	......	......	9,680	17,924				
Minnesota	*	*	*	*	47,480	70,802	......	......	*	*
Mississippi	......	......	*	*						
Missouri	......	......	*	*	......	......	*	*		
Montana	210	315								
New Jersey	......	......	10,000	15,000						
New Mexico	......	......	*	*	......	......	*	*		
New York	......	......	18,180	11,306	91,330	149,081	......	......	5,700	6,000
Ohio	17,210	51,624	205,680	187,630	1,200	1,200	......	......	4,000	4,673
Oklahoma	......	......	......	......	......	......	......	......	*	*
Oregon	......	......	......	......	*	*	......	......		
Pennsylvania	483,160	600,100	......	......	664,060	808,396	242,960	268,826	6,430	18,603
South Dakota	*	*	3,690	3,537	79,220	111,806	......	......	*	*
Tennessee	*	*	......	......	*	*				
Virginia	......	......	*	*	60,750	56,920	76,500	45,919		
Washington	......	......	450	912	197,390	177,530	1,710	922	8,990	4,495
West Virginia	*	*	300	300	9,580	10,771	......	......	*	*
Wisconsin	137,590	181,096	*	*	14,760	16,481	......	......	*	*
Wyoming	......	......	......	......	*	*				
Undistributed	19,570	29,879	261,840	363,549	48,240	59,500	123,900	68,818	39,210	128,236
	718,370	$952,462	526,560	$642,823	2,143,610	$2,333,979	497,020	$436,929	64,680	$164,207

* Included under Undistributed.

BASALT AND RELATED ROCKS (TRAP ROCK) SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1930 BY STATES
(Quantities approximate)

State	Short tons	Value	State	Short tons	Value
California	794,420	$ 903,570	New Jersey	2,412,970	$ 3,313,917
Connecticut	2,337,720	2,440,151	New York	1,235,580	1,989,416
Hawaii	277,520	442,869	Oregon	1,476,050	1,419,734
Idaho	408,500	378,038	Pennsylvania	1,203,370	1,714,137
Maryland	325,100	470,441	Texas	*	*
Massachusetts	1,743,890	1,874,042	Virginia	*	*
Michigan	118,490	202,335	Washington	1,318,720	1,200,323
Minnesota	155,130	302,115	Wisconsin	*	*
Montana	494,560	131,502	Undistributed	230,230	270,441
				14,532,250	$17,053,031

* Included under Undistributed.

Of the total given in the preceding table 39,450 tons, valued at $74,840, are classed as dimension stone, but figures are not available in sufficient detail to distribute them by States.

INDUSTRIES BY STATES

In following pages the distribution, production centers, and uses of basalt, granite, sandstone, and miscellaneous stone are covered briefly by States in alphabetical order. Uses are mentioned only where unusual applications outside the major fields (concrete aggregate, road stone, and ballast) are involved. The stones of each State are covered in the following order: Basalt (trap), granite, sandstone, and miscellaneous stone. Where no mention is made of one or more of these varieties it may be inferred that there are no developments of commercial importance. Similarly, where an individual State is not mentioned, none of the varieties is utilized therein to an extent to merit comment.

Alabama.—The Wisner (Cambrian) quartzite is quarried near Anniston, Calhoun County, and to a smaller extent in Cherokee County, for use as ganister to make silica brick. Ganister is produced also near Birmingham, Jefferson County. The extensive metallurgical industries centered at Birmingham require silica brick for furnace linings.

Arizona.—Large quantities of massive sandstone are quarried near Querino, Apache County for use as riprap. Quartzite (ganister) is quarried in Cochise County for furnace lining. Stone of types included in the miscellaneous group is abundant in Arizona. Decomposed granite is quarried in Gila County, crushed gravel near Phoenix, Maricopa County, and rock known as "caliche" in Pinal County. Caliche is defined as a

form of earthy impure limestone characteristic of the hot arid regions of the Southwest.

Arkansas.—Sandstones and miscellaneous rocks occur in various parts of Arkansas, but chief production is confined to central and western districts. Sandstone has been quarried extensively at Fort Smith, Sebastian County, near the western border of the State. Stone classed as sandstone or argillite is quarried on a large scale at Little Rock, Pulaski County, central Arkansas. Boulders are crushed for road building in this district.

California.—Rocks of many varieties suitable for crushing occur in various parts of California. Chief developments are in the two metropolitan areas, Los Angeles and San Francisco, but numerous quarries have been opened in other localities. Basalts are abundant and give excellent service in building roads and for concrete aggregate. Loose boulders of granite and other rocks occurring in many localities are sources of crushed stone. Volcanic tuff, andesite, felsite porphyry, decayed granite, serpentine, and other rock types of the miscellaneous class are abundant.

Basalt is quarried extensively in the San Francisco district. Quarries nearest the city are in San Francisco and San Mateo Counties and at Richmond, El Cerrito, and Stege, Contra Costa County. Other quarry centers supplying basalt to this populous territory are at Mayfield, Santa Clara County; Napa, Napa County; and Thomasson, Solano County. Large quarries are operated in Sonoma and Lake Counties. Basalt is quarried also in Del Norte County in the extreme northwest. Roofing granules consisting of trap rock are produced in large quantities at Angels Camp, Calaveras County, in east-central California. Santa Barbara is the only county in southern California that produces any considerable quantity of crushed stone classed as basalt.

Granites are abundant. Very large quarries are operated at Logan, San Benito County, to assist in supplying the extensive demands for crushed stone in the San Francisco area. Crushed granite is produced also in Humboldt, Madera, Riverside, and Sacramento Counties. Production of riprap is reported from San Bernardino County.

Sandstone quarrying is likewise centered chiefly near San Francisco. Large quarries are operated at San Rafael and Green Brae, Marin County, and smaller quarries at El Cerrito, Contra Costa County, and Leona and San Leandro, Alameda County. San Mateo County also produces sandstone. The only large center of quarrying in southern California is in Santa Barbara County. Quartzite (ganister) for the manufacture of silica brick is quarried near San Bernardino, San Bernardino County. Some of the basalt and sandstone quarries are temporary and operate for only a year or two to supply stone for special projects.

Bituminous sandstone is obtained in two localities in the State. Fifty-foot beds of Miocene age occur on the coast about 5 miles northwest of Santa Cruz, Santa Cruz County, and Pleistocene asphaltic sands near Carpenteria, in southeastern Santa Barbara County. Materials from both localities have been utilized in highway construction for many years.

Rocks classed as miscellaneous occur very widely in California. Quarries, some of them exceptionally large, are worked in more than 20 counties distributed throughout almost the entire length and breadth of the State. California produces about 70 per cent of all stone classed as miscellaneous quarried in the United States.

Beginning with counties nearest the southern boundary the first commercial rock encountered is a felsite porphyry quarried at Sunnyside, Spring Valley, Otay, and Chollas, San Diego County. Lava and other volcanics also are produced in this county. Altered granite is quarried in Orange County. The most extensive crushed-stone enterprises in the State are in Los Angeles County. Many thousand tons of andesite and decomposed granite are quarried at Avalon on Santa Catalina Island. Stone of various sorts is quarried and crushed at Hollywood, Altadena, Baldwin Park, Culver City, El Monte, Irwindale, Los Angeles, Whittier, and other points; the bulk of it is river-wash boulders and gravel. Activity in so many centers is doubtless due to the rapid growth in population of this region.

A red stone is used for the manufacture of roofing granules in San Bernardino County. Crushed stone is prepared in Santa Barbara County and at Inyokern and Mojave, Kern County. Substantial amounts of volcanic tuff are quarried at Lone Pine and Olancha, Inyo County; and large companies are engaged in crushing boulders at Friant and serpentine at Piedra, Fresno County. Plants of moderate size produce crushed stone at Cathay, Mariposa County; Oakdale, Stanislaus County; and Sacramento and Fairoaks, Sacramento County. The products of the latter county are chiefly boulders and gravel from gold-dredger tailings. The production of miscellaneous stone in the San Francisco district is limited to small quarries in Alameda and Sonoma Counties.

In north-central California production of crushed stone is reported in Lake and Glenn Counties, and very large boulder-crushing operations from gold-dredger tailings are established at Chico and Oroville, Butte County. There are smaller quarries at Truckee and Nevada City, Nevada County, and at several points in Sierra County. At Crescent City, Del Norte County, in the extreme northwest large quantities of schist are employed in harbor work and as crushed stone. Road-building requirements in northern California are supplied in part from indefinitely classified stone quarried at Susanville, Lassan County; Flume and other

points in Shasta County; Weaverville, Trinity County; and Blue Lake, Garberville, and Trinidad, Humboldt County.

Colorado.—Granite, sandstone, and miscellaneous rocks are the chief sources of crushed stone in Colorado. Granites are plentiful and occur near many towns. Basalt is available but is used in small amount.

The largest granite quarry is near Golden, Jefferson County. Sandstone is quarried in Boulder County; at Canon City and other points in Fremont County; and near Stone City, Pueblo County. Of the miscellaneous types phonolite is crushed in Teller County and at Cripple Creek, El Paso County. Volcanic ash or tuff is obtained in Routt County, and a large crushed-stone plant is operated at Trinidad, Las Animas County.

Connecticut.—Basalt (trap rock), occurring in north and south ridges in the central lowland area, is the most prolific source of crushed stone in Connecticut. It is tough and durable and has a high reputation as road material. Granites and granite gneisses abound in both the eastern and western highlands but are not used extensively. Sandstones of the Connecticut River Valley are supplementary sources of raw material.

Very extensive trap-rock quarries, with large modern crushing plants, are operated at many places in central and southern Connecticut. Among the principal centers of activity are Newington, Farmington, Suffield, New Britain, West Hartford, Plainville, and Rockyhill, Hartford County; Cheshire, Hamden, Meriden, New Haven, Wallingford, and North Branford, New Haven County; and Bridgeport, Fairfield County. Small amounts of granite for riprap and concrete aggregate are produced in Hartford, Middlesex, Windham, and New London Counties. The chief center of sandstone production is at Cromwell, Middlesex County.

Delaware.—Rocks in Delaware suitable for crushing are confined almost entirely to granites and gneisses occurring near the northern end of the State. Large quarries for production of riprap, road stone, and concrete aggregate are operated near Wilmington, Newcastle County.

District of Columbia.—Granite gneiss occurring in the northern section of the District of Columbia is quarried locally at times for concrete aggregate and street paving.

Florida.—Very little solid rock other than limestone occurs in Florida. The only output worthy of mention consists of crushed stone, classed as flint, produced at Morriston, Marion County.

Georgia.—The abundant granites of Georgia are crushed in moderate amount, principally as by-products of the paving-block and curbstone industry, at Lithonia, De Kalb County. Crushed granite is produced also at Stockbridge, Henry County; at Toccoa, Stevens County; and in Elbert County. Granite riprap is obtained in Oglethorpe County.

Idaho.—Rocks designated basalt or trap are quarried in northern Idaho, chiefly by the State or counties for highway work. There are quarries near Lewiston, Nez Perce County; and in Latah, Clearwater,

Bonner, Lewis, Benewah, and Kootenai Counties. Some quarries are temporary, being worked for a limited time only to supply stone for special projects. Rock classed in the miscellaneous group is quarried for railway ballast at Crossport, Boundary County, and altered granite is quarried in Clearwater County.

Illinois.—Very little rock other than limestone is used for the manufacture of crushed stone in Illinois. Most sandstones occurring in the State are consolidated too loosely for such use; but a more indurated variety, known as "novaculite," quarried at Tamms, Alexander County, is used for road base. A small amount of ganister also is produced in this county.

Kansas.—Quartzite is prepared for use as concrete aggregate near Lincoln, Lincoln County. An asphaltic sandstone, with a bituminous content of 6 to 12 percent, was quarried actively in and near Pleasanton, Linn County, in 1932.

Kentucky.—The bituminous Kentucky sandstones are the most important bituminous or asphaltic rocks quarried for road building in the United States. As indicated in the table on page 482 compiled by the United States Bureau of Mines, $2,000,000 to $3,000,000 worth is mined annually in Kentucky.

Extensive deposits of the sandstone, which is of Carboniferous age, occur in Edmonson, Breckenridge, Grayson, and Hardin Counties in west-central Kentucky. At Kyrock and Asphalt, Edmonson County, the commercial beds, which are quarried throughout the year, are about 20 feet thick and covered with 40 to 60 feet of sandstone overburden. The latter is blasted, loaded with steam shovels, and removed as waste. After blasting the bituminous rock is loaded by hand to permit careful selection. A large output has been maintained for many years. The product is shipped by barges to railway lines, either at Bowling Green or Rockport, and is marketed in at least 35 States. The bituminous content of the stone as shipped to customers is a little over 7 per cent. Other production centers are Elizabethtown and Summit, Hardin County; and Big Clifty and Leitchfield, Grayson County; all have railroad facilities.

Maine.—Both granite and trap rock are quarried near Portland, Cumberland County. Quarries producing granite as dimension stone in Franklin, Hancock, and York Counties supply a small amount of by-product crushed stone and riprap. Miscellaneous types are crushed at Lewiston, Androscoggin County, and at various points in Cumberland, Somerset, and other counties.

Maryland.—Basalt is an important source of crushed stone in Maryland. Several large quarries are operated at Woodlawn, Loch Raven, and other points in Baltimore County. Crushed stone and riprap are obtained at Port Deposit, Cecil County. Very large quarries, chiefly

NATIVE BITUMINOUS OR ASPHALTIC ROCK SOLD IN THE UNITED STATES 1926–1930*
(Value f.o.b. mine)

	1926		1927		1928		1929		1930	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Bituminous rock:										
Alabama	22,000	$101,000	32,650	$128,700	110,360	$406.575	77,209	$258,886	79,980	$297.211
Oklahoma	37,010	121,830	42,460	132,380						
California	3,330	19,310								
Kentucky	320,430	2,530,480	344,220	3,156,700	318,548	2,757,547	340,346	2,785,772	305,024	2,374,834
Texas	289,980	825,610	376,770	1,254,500	321,505	815,482	320,931	946,003	270,138	825,460
Utah	......	....	....	....	10,084	80,672	10,064	80,512	9,729	69,090
Total	672,750	$3,598,230	796,100	$4,672,280	760,497	$4,060,276	748,550	$4,071,173	664,871	$3,566,595

* Occurrences in other States mentioned in this table are covered in descriptions of the stone industries in the respective States—Alabama and Texas in chapter XVII, and California, Oklahoma, and Washington in chapter XVIII. Data by States later than 1930 incomplete.

for the production of railroad ballast, operate on a bluff overlooking the Susquehanna River near Havre de Grace, Harford County. Granite is quarried near Baltimore and at Blue Mount and other points in Baltimore County. Crushed stone is produced as a by-product of a dimension-granite enterprise in western Baltimore County near Woodstock and in southern Montgomery County near the District of Columbia. Ganister is produced near Corrigansville, Allegany County. Crushed stone of miscellaneous types, including serpentine, is quarried near Baltimore.

Massachusetts.—Basalt is the rock most widely used for crushing in Massachusetts. There are more than 20 important centers of production, and several quarries are among the largest in the United States. Extensive market demands in the Boston metropolitan area and in nearby cities are met from quarries at Lawrence, Beverly, Methuen, Salem, and Swampscott, Essex County; and at Holliston, Pepperell, Sherborn, Newton, Stony Brook, and Winchester, Middlesex County. The largest plants are at the two last locations and at Swampscott. Quarries are numerous in western Massachusetts. Many thousand tons of crushed basalt are produced at Westfield, West Springfield, and Holyoke, Hamden County. Other important quarry centers are at Amherst, Hampshire County; and Greenfield, Franklin County.

Granite is quarried extensively in several eastern counties. Crushed stone and riprap are produced at Salem, Rockport, Bay View, and Pigeon Cove, Essex County. A very large quarry, chiefly for production of road stone, is operated at West Roxbury, Suffolk County. The well-known Quincy district of Norfolk County, where large amounts of monumental and building granites are quarried, also provides many thousands of tons of crushed granite. Other quarries operate in Plymouth County; and at Acushnet and Westport, Bristol County.

Miscellaneous rocks contribute materially to the large output of crushed stone in eastern Massachusetts. Rock classed as felsite is quarried extensively at Saugus, Essex County, while flint stone and other rocks are crushed at Southbridge, Worcester County. Rocks of volcanic origin are quarried at Malden, Middlesex County, and at Roslindale and Revere, Suffolk County. A conglomerate is crushed at Jamaica Plain and West Roxbury, Suffolk County.

Michigan.—There are two important centers of basalt production in the northern peninsula of Michigan. Crushed basalt is used in highway and street paving in and near Ishpeming and Negaunee, Marquette County. A quarry at Negaunee provides stone for the manufacture of granules used in the same way as slate granules for surfacing prepared roofing. Considerable quantities of crushed basalt are produced at Wakefield, Gogebic County. Crushed basalt is produced also in Houghton and Iron Counties. Sandstone quarried near Marquette, Marquette County, is used in highway construction.

Minnesota.—Basalt is applied to commercial use in St. Louis County, northeastern Minnesota. Massive occurrences at Duluth and Biwabik are quarried for highway work and concrete aggregate. Basaltic rock is quarried at Ely for the manufacture of roofing granules.

Granite is quarried for road stone at Two Harbors in southern Lake County. A very extensive block-granite industry is centered in Stearns County, and waste from this district is utilized to some extent for the manufacture of crushed products.

Sandstone is, or has been, utilized in three localities. Crushed stone is produced at Sandstone, Pine County, in conjunction with a large paving-block, curbing, and building-stone industry. The Sioux quartzite, of Huronian age, is crushed at times for concrete aggregate at Pipestone, Pipestone County, and at Jasper and Luverne, Rock County, in the southwestern corner of the State. Quartzite quarried at Pipestone is also manufactured into roofing granules. A northeastern extension of the Sioux quartzite has been quarried for crushed-stone manufacture at New Ulm, Nicollet County.

Missouri.—A small output of crushed granite is reported from Graniteville, Iron County, and from Wayne County. Sandstone riprap is obtained from quarries at Miami Station, Carroll County. Of the miscellaneous varieties flint is crushed for concrete aggregate in Greene County, rhyolite for road stone at Pilot Knob, Iron County, and "chats" (siliceous gangue) in the lead-zinc districts.

of the largest quarries in eastern United States is at Bound Brook, Somerset County. Other important operations in this county are at Millington, North Plainfield, Scotch Plains, and Westfield. Very large crushing plants are located at Summit, Union County; and at North Bergen, Hudson County. Extensive activities at South Orange, West Orange, and North Caldwell supply the populous centers of Essex County. At least 10 large quarry companies were operating in Passaic County in 1930; the chief centers are Richfield, Great Notch, Little Falls, Hawthorne, Clifton, and Paterson. Quarrying at various points along the palisades of the Hudson River in Bergen County has been discontinued, because it detracts from the scenic beauty of the river; but one large quarry is still operated at Cliffside Park.

Rock approaching a granite in composition is quarried near Pompton Lakes, Morris County, and sandstone is utilized as riprap in Hunterdon County. Argillite (a firmly consolidated, massive shale), which is employed extensively for local building purposes at Princeton, Mercer County, is also crushed for use as concrete aggregate.

New Mexico.—Crushed sandstone for railroad ballast is obtained from a large quarry in Socorro County near Scholle. A large plant was under construction in 1932 near Santa Rosa, Guadalupe County, for production of asphaltic sandstone to be used in highway work. A rock known as "caliche," a form of earthy limestone characteristic of arid regions in the Southwest, is quarried for road building in Mora County.

New York.—Basalt is quarried extensively in Rockland County, New York, in a northward extension of the palisade trap rock of New Jersey. One of the largest quarries for production of crushed stone in eastern United States is at Haverstraw, and there are other large quarries at West Nyack and Suffern.

Granite is quarried in several counties in eastern and southeastern New York. Road stone is produced in Westchester County near New York. Farther north along the Hudson River crushed granite is prepared for use at a large quarry near West Point, Orange County, and riprap is produced in Washington County as occasion demands. Granite is crushed for road building at Altamont, Albany County. One of the largest quarries in the State for production of crushed granite is at Little Falls, Herkimer County. Other quarries are in Hamilton County; at Elizabethtown, Keene, Keesville, and Lake Placid, Essex County; and at Alexandria Bay, Jefferson County.

Sandstone is quarried in many parts of New York. Rock, some of which is red and useful for surfacing private roads and walks, is quarried at Central Valley, Thompson Ridge, and other points in Orange County. Bluestone is crushed for road stone and riprap in Sullivan County. Sandstone, used principally for road stone, is quarried at Greensville, Greene County; New Salem, Albany County; and Schenectady, Sche-

nectady County. Other quarries are at such widely separated localities as Steuben County in south-central New York and Oswego County near the eastern end of Lake Ontario. The Medina sandstone, which is utilized extensively for the manufacture of paving blocks and curbing, is crushed for road base and concrete aggregate at Albion and other places in Orleans County and at Lockport, Niagara County.

North Carolina.—Granite, the most important source of crushed stone in North Carolina, is utilized in many western and northern counties. Developments of importance farthest west are in Buncombe County, chiefly at Asheville and Swannanoa. Large quarries are worked at Hiddenite, Alexander County; at Winston-Salem, Forsyth County; and at Charlotte, Mecklenburg County. Concrete aggregate and railroad ballast are manufactured at Mount Airy in Surry County as by-products of the extensive building-stone, paving-stone, and curbing industry centered in that locality. Granite Quarry and Salisbury, Rowan County, are important sources of crushed granite. Large quarries are worked in several north-central counties. The principal centers are Stacey, Rockingham County; Stokesdale, Guilford County; Chapel Hill, Orange County; Greystone, Vance County; Wake Forest, Wake County; and Sims, Wilson County. Crushed stone classed in the miscellaneous group is quarried near Durham, Durham County.

Ohio.—Rocks other than limestone occurring in Ohio are of little importance for crushing compared with the enormous limestone resources of the State. The extensive block-sandstone industries of Amherst, Lorain County, and Euclid, Cuyahoga County, produce considerable sand as a by-product. It is used as building sand and in foundries and steel mills. The building-sandstone industry at McDermott, Scioto County, produces riprap as a by-product. Sandstone has been quarried for concrete-aggregate manufacture in Athens and Tuscarawas Counties. Rock classed in the miscellaneous group is crushed at Mifflin and Jeromesville, Ashland County, and boulders are crushed for road stone and concrete aggregate in Clermont County.

Oklahoma.—Crushed granite and riprap are produced at Granite, Greer County, and crushed sandstone has been produced in Coal County. Asphaltic sandstone of Ordovician age is quarried near Dougherty, Murray County. A bituminous limestone obtained near the same locality is mixed with the sandstone and the mixture used for highway and street paving.

Oregon.—Basalt is abundant and widely used in Oregon, chiefly in the western counties. It is an important source of raw material for highway construction throughout the western third of the State and also in Wallowa County, in the northeastern corner. Oregon is characterized by a large number of small or moderate-size quarries, the aggregate annual production of which is in times of normal prosperity valued at about

$1,500,000. In the following brief outline of quarry centers, many regions having relatively small production are omitted.

In the northwestern corner of the State basalt is quarried at Jewell and Astoria, Clatsop County; and at Mist, Clatskanie, Saint Helens and other places, Columbia County. Riprap is an important product in the latter locality. Other quarry centers in the northwestern area are Blaine and other points in Tillamook County; Hillsboro and Reedville, Washington County; Yamhill and Gaston, Yamhill County; Portland and vicinity, Multnoma County; Barlow, Clackamas County; Albany, Brownsville, and Holley, Linn County; Alsea and Corvallis, Benton County; The Dalles, Wasco County; and Wasco, Sherman County. Many basalt quarries are or have been worked in southwestern Oregon, principally at Ashland and Eagle Point, Jackson County; Crater Lake and Klamath Falls, Klamath County; Yoncalla and Drain, Douglas County; and Mapleton, Paris, Alma, and several other localities in Lane County. In Wallowa County, in the northeastern corner of the State, basalt is quarried at times at Lastine, Flora, and Wallowa.

Sandstone is quarried as occasion demands for highway work and concrete aggregate in Coos and Washington Counties. Immense quantities of sandstone riprap for breakwaters are quarried at Marshfield, Coos County; Reedsport, Douglas County; and Florence, Lane County. A number of both basalt and sandstone quarries are temporary in character, operating only a year or two to supply stone for special projects.

Pennsylvania.—Sandstone and quartzite are the most important rocks other than limestone used in crushed or broken form in Pennsylvania. Large quantities of basalt are quarried, while granite and miscellaneous rocks are utilized in smaller amounts.

Basalt or trap rock is confined to the southeastern part of the State. Large, well-equipped quarries producing thousands of tons of crushed stone for railroad ballast, concrete aggregate, and highway construction are located at Glen Mills, Delaware County; Quakertown and Rockhill, Bucks County; and Birdsboro, Berks County. Other basalt quarries are at Elizabethtown, Lancaster County, and at several points in Montgomery County. Roofing granules are manufactured extensively from basalt and other igneous rock at Greenstone and near Charmian, Adams County.

Granite of present commercial importance is restricted in occurrence to the extreme southeastern corner of the State. Much so-called granite is banded and therefore more correctly classified as gneiss. One of the more important quarry centers is at Glenmoore, Chester County, but substantial amounts are obtained in Philadelphia, Delaware, Montgomery, and Berks Counties.

Large amounts of sandstone are produced for riprap and ordinary crushed-stone uses, while in production of ganister, a form of quartzite,

Pennsylvania leads all States by a wide margin. Sandstone-crushing plants are scattered widely throughout the State. In directing attention first to eastern activities mention may be made of quarries producing riprap and concrete aggregate at Lumberville and Neshaming Falls, Bucks County, and also in Berks and Dauphin Counties. Both basalt and granite are of much greater importance than sandstone as sources of crushed stone in the southeastern counties. In northeastern Pennsylvania sandstone is quarried in Pike County; at Scranton, Lackawanna County; and at Wilkes-Barre, White Haven, Hendler, and other points in Luzerne County. The crushed-sandstone industry of east-central Pennsylvania is represented by quarries at Dalmatia and Shamokin, Northumberland County, and by small road-stone quarries in Lycoming County. In the central area large quarries are operated for railroad ballast and concrete aggregate production at Williamsburg, Blair County; and at Water Street, Huntingdon County. A small output of crushed sandstone has been reported in Indiana County in west-central Pennsylvania, and quite extensive operations are conducted at Connellsville, Dunbar, and Coolspring, Fayette County; and at McCance and Torrance, Westmoreland County.

Ganister is quarried most extensively in central Pennsylvania, although considerable quantities are obtained in other parts of the State. "Floe" rock, occurring chiefly at high levels in the mountains and consisting of talus-slope boulders, is obtained in great quantities at Williamsburg, Claysburg, Flowing Spring (post office, Canoe Creek), Sproul, and McKee, Blair County; Alexandria, Barree, Mount Union, Water Street, and Neelyton, Huntingdon County; Port Matilda, Center County; and Lewistown, Mifflin County. Ganister is quarried at Columbia, Lancaster County, in southeastern Pennsylvania; Layton, Fayette County, in the southwest; and New Castle, Lawrence County, near the western border. A small supply is obtained at times in Indiana County.

One of the most important of the miscellaneous rocks is mica schist quarried chiefly for furnace lining at Edge Hill, Glenside, and other points in Montgomery County. Argillite is quarried at Perkiomenville and Sanatoga in the same county; near Gettysburg, Adams County; and at many places in Berks County. Serpentine is crushed for terrazzo manufacture at Quarryville, Lancaster County. Immense quantities of boulders and other miscellaneous varieties of stone were produced in numerous wayside quarries for secondary road construction during 1932.

Rhode Island.—Crushed granite is produced as a by-product of a granite dimension-stone industry at Bradford near Westerly in the southwestern corner of Washington County. Granite is quarried and crushed at Bristol, Bristol County, and at Newport and other points in Newport County. A conglomerate rock is also quarried near Newport.

Serpentine rock is crushed for road building at Cranston and Providence, Providence County. Rock, designated by some as trap, also occurs in this county and is quarried at Berkeley, Diamond Hill, and Woonsocket for use as concrete aggregate and road stone.

South Carolina.—Granite is the only rock used for the manufacture of crushed and broken-stone products in South Carolina. The larger operations are in the central and western parts of the State. The quarry of largest output in northeastern South Carolina is at Pageland in northern Chesterfield County. Large, productive quarries are located in an area near the center of the State. The more important are at Blairs, Fairfield County; Columbia, Richland County; and Cayce, Lexington County. While crushed stone is the chief product a minor output of riprap is reported from this district. Except for a quarry of major proportions at Trenton, Edgefield County, near the western border of the State, chief activity outside the central district is in the extreme northwest. Large quarries for production of road stone and concrete aggregate are at Liberty, Pickens County, and at Hellams, Greenville County, while smaller quarries are worked in Oconee and Spartanburg Counties.

South Dakota.—Granite quarried at Rapid City, Pennington County, is used as crushed stone and also for filter beds in sewage plants. Sandstone is quarried for road construction and concrete aggregate in Hanson County; and at Dell Rapids and Sioux Falls, Minnehaha County. Ganister for furnace lining and furnace sand is obtained in both the last-named localities. Rock classed as porphyry is used as a source of crushed stone at Lead and other points in Lawrence County.

Texas.—Prominent rounded knobs of trap rock stand out prominently on the plains of Uvalde County, in southern Texas. They are quarried extensively at Knippa, chiefly for railroad ballast. Riprap is produced near Marble Falls, Burnet County, in central Texas, as a by-product of a building and monumental granite industry. Sandstone is quarried for breakwaters at Huntington, Angelina County; and for both riprap and roadstone near Huntsville, Walker County.

The principal Texas rock classed in the miscellaneous group is "caliche" which is quarried at Skidmore, Bee County; and at Realitos, Duval County, in southern Texas; also in El Paso County and at Allamoore, Hudspeth County, in the far west. Rock of uncertain type is used for road construction at Pittsburgh, Camp County. Volcanic tuff is quarried in Martin County and unclassified rock at Mathis, San Patricio County. Portable crushing plants are operated in various counties, as occasion demands.

Utah.—Asphalt-bearing sandstone of Eocene age is quarried in the Book Cliffs near Sunnyside, Carbon County. Stone is lowered 3,000 feet over a 3-mile tramway to a terminal base in Whitmore Canyon.

It is crushed at Sunnyside and shipped by rail for road-building purposes. Rock classed in the miscellaneous group is manufactured into roofing granules in Salt Lake County.

Vermont.—Although Vermont produces very large quantities of monumental granite the output of crushed material is quite small. One of the large companies producing dimension stone at Websterville, Washington County, crushes granite waste and markets it as a by-product. Small amounts of crushed granite and riprap for railroad use are produced at other quarries in this county. At West Dummerston, Windham County, and Bethel, Windsor County, a small part of the waste at block-granite quarries is crushed for concrete aggregate and road stone.

Virginia.—Trap rock is sometimes quarried in eastern Loudoun County near Ashburn. Crushed granite is produced near Culpepper, Culpepper County, and in Albemarle County. Large quarries are operated for production of railroad ballast, road stone, and concrete aggregate near Richmond, Henrico County; and at Boscobel, Goochland County. The largest granite quarry in the State, at Skippers, Greensville County, produces many thousands of tons of railroad ballast. Sandstone is crushed in southern Augusta County near Waynesboro, and there are small quarries in Bath and Highland Counties in west-central Virginia.

Washington.—Basalt, chiefly of Tertiary age, is a very important source of crushed stone in Washington. The rock is distributed very widely and quarried in more than 20 counties. In southeastern Washington crushed basalt is produced in Asotin, Garfield, and Franklin Counties; at Dayton, Columbia County; at Lamar, Walla Walla County; at Pullman, Penawawa, Rosalia, Palouse, Colfax, and Colton, Whitman County; and at Prosser, Benton County. Spokane County, in eastern Washington, is an important producer, with quarries at Rockford, Plaza, Medical Lake, Fairfield, and Mead. Pond Oreille County in the northeast, Okanogan County in the north, and Kittitas and Grant Counties in the central area are moderate producers. Both riprap and crushed stone are produced at North Bend and other points in King County; at Charleston, Kitsap County; and in Pierce County, in the west-central region. There are numerous quarries in southwestern Washington. Some of the active centers are Long Beach, South Bend, and Seaview, Pacific County; Doty and Divide, Lewis County; and Stella, Cowlitz County. Yakima, Yakima County, and Goldendale, Klickitat County, are production centers in southern Washington. Some quarries are temporary, operating for only a year or two to supply stone for special projects.

Granite quarrying is confined to an area near the center of the State where small to moderate-size quarries are operated at Lakeside and

Entiat, Chelan County, and in southern Douglas County near Trinidad and Wenatchee. Sandstone occurs in west-central and northwestern Washington. A little riprap is produced at Wilkeson, Pierce County, as a by-product of a cut-stone industry. A total production of some magnitude is obtained from the operation of portable crushers scattered throughout various counties.

West Virginia.—Sandstone is the only rock other than limestone used for crushing in West Virginia. Normally the most important sandstone activity is the production of ganister at Berkeley Springs, Morgan County. Concrete aggregate and road stone are produced at Charleston, Kanawa County, and in Ohio County. Several sandstone quarries are operated intermittently by the State.

Wisconsin.—The only important trap-rock-quarry region in Wisconsin is at Dresser Junction, Polk County, on the western border. Minneapolis and St. Paul, Minn., are important markets for the products of stone crushers in this territory. Crushed or broken granite is produced principally in the regions where monumental stone, building granite, and paving blocks are manufactured, and much of it is a by-product of these industries. Riprap and crushed granite are quarried at Lohrville and Redgranite, Waushara County, and to a smaller extent in Green Lake and Juneau Counties. Small quantities of sandstone riprap constitute part of the output of Dunn County as a by-product of a building-sandstone industry. Quartzite (ganister) for manufacture of silica brick and furnace linings is produced near Ableman, Devils Lake, and North Freedom and crushed quartzite for road work at Ableman and Baraboo, all in Sauk County, in southern Wisconsin. The Baraboo quartzite is also used for the manufacture of granules. Crushed stone, classified in the miscellaneous group, is quarried for highway construction in Wood County.

Wyoming.—Sandstones occurring in Carbon and Platte Counties are crushed for road building and concrete aggregate.

QUARRY METHODS AND EQUIPMENT

Methods of quarrying and preparing limestone for various markets have been described in some detail in the preceding chapter. For types of rock other than limestone the general procedure differs in no material respect, therefore repetition of the various steps is unnecessary. Attention will be directed merely to certain differences between limestones and other rocks and the influence these differences exert on equipment and methods.

Granites and trap rocks are much harder than limestones. Depending upon their degree of cementation, some sandstones are also much harder than average limestone, while others work quite easily. Drilling in any of the harder varieties of rock is slower than in limestone, and the

drill steel wears rapidly, therefore drilling costs are comparatively high. Heavy charges of dynamite are required for the tougher varieties.

Crushing equipment must ordinarily be sturdier than that for limestone. The abrasive action of the more siliceous stones wears out the contact parts of crushers, screens, and elevators rather rapidly.

For these reasons quarry costs are generally somewhat higher for siliceous rocks than for limestone. According to a report on quarry costs prepared by Thoenen,[72] average direct costs, including crushing and screening, are 75 cents a ton for trap rock, $1.08 a ton for granite, and 97 cents a ton for sandstone compared with an average limestone quarrying and crushing cost of 56 cents a ton. These are general averages and include quarries of all sizes. Operators of the larger and more completely equipped quarries may reduce costs somewhat below average figures, while smaller and less completely mechanized plants may have somewhat higher costs.

As pointed out in the introductory part of this chapter, waste limestone finds much wider use than waste stone of other types. Therefore, for quarrying and crushing rocks other than limestone efforts are directed toward obtaining explosives and equipment best-adapted for preparing a high proportion of marketable sizes, with a minimum of fines.

MARKETING

Marketing problems differ in no essential respect from those of limestone. Trap rock has a high reputation for road construction and finds its best market in that field. Granite is used less widely in highways but is employed in large quantities for concrete aggregate, railroad ballast, and riprap. Sandstone also is marketed most extensively for the last uses, although it is used to some extent for road base. Miscellaneous rocks enter many fields of utilization, which are so diversified that no general statements may be made regarding the scope of their markets.

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